SENSITIVITY STUDY OF THE XR-3 LOADS AND MOTIONS COMPUTER PROGRAM SIDEWALL PARAMETERS AND FORCES ON ROLL BEHAVIOR IN CALM SEA AND A COMPARISON TO TESTCRAFT TURN MANEUVER DATA

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THESIS

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by

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Thesis Advisor: Alex Gerba, Jr.

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I. INTRODUCTION

A. Background

In the past several years the Surface Effect Ship (SES) has received increased attention in the United States Navy and detailed investigations of its sea performance have been carried out. The two major categories of SES are the Air Cushion Vehicle (ACV) and the Captured Air Bubble Ship (CAB). The CAB-type of craft has become of primary interest to the United States Navy and two of the constructed testcrafts are the Bell Aerospace Systems 100-B and the XR-3 of approximately 100 and 3 tons of displacement, respectively. In 1976 the U.S. Navy Surface Effect Ship SES 100-B of the CAB-type established a world speed record for surface type ships of 89.4 knots. In April 1976 the SES 100-B launched a missile at 60 knots. The launch was successful and the missile hit its target five miles away.

In order to investigate the characteristics of the CAB-type SES under any design and operating conditions without the costly need of modifying the actual craft, a Loads and Motions digital computer program was developed by Oceanics, Inc. [Ref. 1]. In 1970 the XR-3 testcraft was delivered to the Naval Postgraduate School and Leo and Boncal converted the 100-B Loads and Motions program to represent the XR-3. Since there were substantial design differences between these two ships programming modifications were required in certain subroutines.

B. Objectives

The purpose of this thesis is to investigate one aspect of safe maneuverability of these high speed ships, i.e. their roll behavior in a turn maneuver. To fulfill this objective the sensitivity of the simulated XR-3 roll behavior in turn maneuvers as it is represented by the Loads and Motions Program is investigated for its dependence on changes in sidewall characteristics. The effect of modifications in the added mass computation, sidewall parameters and force calculations as well as propulsion and rudder input parameters are investigated. An evaluation of the computed performance is obtained by comparison with experimentally measured steady state roll conditions.

II. INITIAL REMARKS

A. PROBLEM OF REPEATABILITY

It has been this author's experience as well as all previous investigators at the Naval Postgraduate School using the XR-3 Loads and Motions Program that there have been no observed problems related to repeating the results for a given input condition. However, during the author's first studies of the Loads and Motions Program as listed in Menzel's thesis [Ref. 2] an attempt was made to duplicate some of the simulation runs given in that reference work. It was found necessary as a first step to restore the simulation program on the IBM 360/67 computer from a card source onto a disk.[1] Using the input conditions stated in Ref. 2 it was impossible to obtain identical time histories, e.g. for turns. Each time subroutine SIDEWALL was read into the computer together with the data input deck, thereby overriding the stored program, an error message in the printed output indicated that a division by zero occurred in this subroutine. The error message was not generated when the stored program which contained an identical version of subroutine SIDEWALL was called. A closer look revealed that in the SIDEWALL-version given in Ref. 2 the variable PBAR (plenum pressure) was neither

[1] It should also be noted that results obtained in Ref. 2 used the IBM 360/67 Release 20.6 system while the results obtained in this work used the 21.8B Release with HASP installed.

defined nor transferred by a COMMON-statement and therefore a default value of zero was used during the computation of PBHEAD (see Appendix C, SDWL 0440). The missing statement

PBAR = PB - PINF

was inserted to subroutine SIDEWALL. With this correction the new results were slightly closer to those given in Ref. 2.

The table given below compares output values for roll and pitch angle in a turn at 20 kn with constant thrust and a 35 degrees rudder step input under calm sea conditions.

TABLE I

20 kn turn at 35 deg rudder angle

	without PBAR-card	with PBAR-card	Ref. 2	relative deviation
Roll angle (deg)				
first peak	7.44	7.39	7.2	2.6 %
avrg at 20 sec	2.65	2.77	3.1	11.9 %
Pitch angle (deg)				
first peak	1.34	1.33	1.2	9.8 %
avrg at 20 sec	0.99	0.94	0.8	14.9 %

Although the differences between columns 2 and 3 in TABLE I might be considered to be small as far as magnitudes are concerned , the relative deviation is up to 15 % as shown in column 4. But what is more important is the fact that the roll and pitch angle responses for the uncorrected (plots 1 and 2 in Appendix A) as well as for the corrected program (plots 3 and 4) show an unstable craft behavior for t>40 sec where the pitch angle increases rapidly while the roll angle

decreases rapidly approaching the zero degree value. This unstable condition is probably due to the 35 degrees rudder step input at 20 kn, as it is used in Menzel's study, which is physically unreal since it could never be introduced to the XR-3 testcraft in an actual run at that speed. Therefore rudder angles of up to 15 degrees introduced at a rate of 5 deg/sec will be used throughout this work, as it is also done on the testcraft.

Also, regarding plots 1-4 again and not considering whether they really reflect the actual craft behavior, it should be noted that a short time history (t<20 sec in Ref. 2) could possibly result in wrong conclusions because the unstable condition is not evident at that instant of time. Therefore, time histories of up to 40 or 50 seconds will be shown throughout this study.

B. STEADY STATE CONDITIONS

Due to the change in subroutine SIDEWALL as mentioned in the preceding section the steady state conditions for straight runs in calm water have been reestablished for various speeds and are listed in Table II.

Table II
Steady State Conditions

Speed (kn)	Draft (in)	Pitch angle (deg)	Plenum pressure (psf)	Thrust (lb)
10.0	8.17	1.62	23.93	400.61
12.5	7.03	1.11	24.84	349.42
15.0	6.74	0.84	24.84	335.71
17.5	6.41	0.63	24.84	346.45
20.0	6.12	0.48	24.84	373.44
22.5	5.87	0.36	24.84	411.53
25.0	5.66	0.29	24.84	458.62
27.5	5.48	0.25	24.84	513.31
30.0	5.34	0.26	24.84	574.43

These steady state conditions have been established by first executing the XR-3 Loads and Motions Program with constant speed for 40 seconds and then repeating the run keeping the evaluated thrust constant. A comparison of these steady state values with those given in Ref. 2 shows differences especially in the lower and upper speed range of again up to 15 % the cause of which could not be suspected anywhere else since the simulation program has not been changed since last used by Menzel.

C. SIGN CONVENTIONS

The sign conventions used in the XR-3 Loads and Motions Program are identical to those used in Report 71-84 by Oceanics Incorporated [Ref. 1]. A right handed coordinate system is applied to the craft with the positive X-axis being measured forward and the lateral Y-axis being measured positive to starboard. The vertical Z-axis is measured positive downward. Identical signs are used for respective forces along those axes.

The signs of the angles are defined in the following manner :

pitch angle being positive upward
(boat noses up)

roll angle being positive to starboard
(boat rolls to starboard)

yaw angle being positive to starboard
(boat turns to starboard)

rudder angle being positive to port
(right rudder, boat turns to port) .

Zero pitch and roll angle are referenced to the X-Y plane parallel to the water surface.

III. INVESTIGATION OF SIDEWALL EFFECTS

A. ADDED MASS EFFECT

1. Theory

A basic element in representing the hydrodynamic forces by use of slender body theory are the two-dimensional sectional values of lateral added mass A22 of the sidewalls, which are necessary for the determination of the lateral forces, as well as the two-dimensional sectional vertical added mass A33 which is also used in determining the roll moment. These two-dimensional added mass values are given in the 'Surface Effect Ships Aero/Hydrodynamics Technology Design Manual' [Ref. 3] as

$$A22 = C_h*RHO*PI*D*D/2.0$$

and

$$A33 = C_v*RHO*B*B/8.0$$

where C_h is the lateral added mass coefficient

C_v is the vertical added mass coefficient

RHO is the specific density of sea water

D is the local draft

and B is the width at the local sidewall waterline.

The C_h and C_v values originally selected in Ref. 1 were those corresponding to high speed with C_h=0.4 and C_v=1.0. But in order to account for variations in sidewall shape, and their influence on the effective lateral added mass, the results of the research work described in Ref. 3 led to an average value of C_h=0.8. This new coefficient improved the agreement between theoretical and experimental data as stated in Ref. 3 . In the present XR-3 Loads and Motions Program a value of C_h=0.4 is used in accordance with Ref. 1 and the effect of letting C_h=0.8 will be investigated in later parts of this thesis.

Considering the equation for the vertical added mass A33, a major difference has been found between that one given in Ref. 3 and the one used in the XR-3 Loads and Motions Program (e.g. Ref. 2), where in accordance with Ref. 1 (1971) there was an additional PI-factor in the A33s equation. The letter 's' indicates that the computation of the added mass is done at the craft's stern. Since Ref. 3 (1976) reflects the experimental and theoretical work being done based on Ref. 1, the A33s equations in subroutines SIDEWALL and SIDETAB have now been changed to the new form given above.

2. New Steady State Conditions

The change in the simulated XR-3 performance due to the reformulated A33s computation can be observed from TABLE III giving the new steady state conditions for straight runs in calm sea for various speeds which are identical for both (0.4 and 0.8) lateral added mass coefficients.

TABLE III

Steady state conditions

(new A33s)

Speed (kn)	Draft (in)	Pitch angle (deg)	Plenum pressure (psf)	Thrust (lb)
15.0	6.80	0.86	24.84	336.30
17.5	6.46	0.65	24.84	347.23
20.0	6.17	0.49	24.84	374.38
22.5	5.92	0.37	24.84	412.62
25.0	5.71	0.30	24.84	459.90
27.5	5.53	0.27	24.84	514.89
30.0	5.40	0.28	24.84	576.66

Comparing these steady state values with those previously given in TABLE II in Sect. II.B one finds in general for all speeds that

- draft has increased by about 0.05 in (0.8 %)
- pitch angle has increased by 0.02 deg (2 to 7 %)
- thrust has slightly increased by less than 0.5 % .

3. Effect in a Turn maneuver

The effect of the change in the formulation of the vertical added mass in a simulated turn maneuver has been studied next. After a 5 sec straight run at 20 kn in calm sea a port rudder deflection was introduced at a rate of 5 deg/sec and then kept fixed at 15 degrees resulting in a turn to port. The deadrise forces are computed at the transom. In TABLE IV are shown the steady state conditions and the roll moments contributed from the bow seal (FKBS), stern seal (FKSS), sidewalls (FKSW), rudder (FKRUD), propulsion system (FKP), aerodynamics (FKAED) and plenum pressure (ABPB*PHI*Z).

TABLE IV

Steady state conditions in 20 kn turn

15 deg port rudder angle

		old A33s	new A33s	deviation
pitch angle	(deg)	0.48	0.52	8.3 %
roll angle	(deg)	2.0	1.98	- 1.0 %
draft	(in)	5.86	5.94	1.4 %
speed	(kn)	19.25	19.27	0.1 %
moments:				
	FKBS	-391.1	-386.3	- 1.2 %
	FKSS	- 3.6	- 3.6	0.0 %
	FKSW	191.0	202.0	5.8 %
	FKRud	- 97.5	-110.0	-12.8 %
	FKP	0.2	0.2	0.0 %
	FKAed	- 54.4	- 53.5	1.7 %
	ABPB*PHI*Z	355.4	351.9	1.0 %

From TABLE IV it can be seen that, due to the modified A33s computation, the counteracting roll moments from the sidewall (FKSW) and rudder (FKRUD) changed by about 6 and 13 %, respectively, resulting in only a little effect in generating a tendency toward a smaller roll angle which is directed out of the turn. Other major contributions to the roll angle are from the bow seal (FKBS directed into the turn) and from the plenum pressure (ABPB*PHI*Z) directed out of the turn. The corresponding plots (plots 5 - 8 for old A33s, plots 9 - 12 for new A33s) show that with the new equation for A33s the pitch and roll angle response curves are less damped than they were using the former equation for vertical added mass calculation as would be expected.

It should be noted that the roll moment due to rudder is fairly large and changes quite significantly while the moment contributed by the propulsion is very small and constant. The cause of this will be investigated in chapter IV.

B. DEADRISE ANGLE

1. Background

Surface Effect Ships (SES) of the captured air bubble type (CAB) have rigid sidewalls immersed into the water, thereby - together with the bow and stern seal - capturing the air in the plenum chamber and reducing air leakage. Since the sidewalls of the XR-3 are not uniform in cross-sectional shape throughout their length but are curved on the outboard side near the bow similar to a single hull ship, the expression "sidehulls" would be more appropriate, as can be found in modern literature.

The importance of the correct understanding of the effect of the sidewalls on the craft's performance is readily seen from a report on SES Research with the XR-1 testcraft [Ref. 5]. As reported, the first test series were carried out successfully with a 45 degrees sidewall deadrise angle, which is the angle between the horizontal plane and the ship's outer sidewall surface. In 1964, after a modification of the craft to 60 degrees deadrise angle and articulating seals, an unstable roll condition occurred during a turn at 35-37 knots, a maneuver performed many times before. The testcraft heeled out of the turn , nosed down due to the retraction of the bow seal, continued its outward roll motion and then flipped over. The report, however, does not mention the rudder action generating the turn. After this accident, the deadrise angle had been changed back to 45 degrees. From this experience the surface effect ship's roll stability should be expected to

be sensitive to the deadrise angle and an investigation of this sensitivity is reported in the following sections.

2. Forces due to Deadrise Angle

The deadrise angle, as pointed out by Ref. 3 and 4, has a major effect on the craft's roll motion and therefore is an important design consideration. During a turn the craft is desired to heel inboard, thereby minimizing the apparent transverse acceleration (a coordinated turn). For typical SES designs, it is not possible to achieve perfect coordination, but it is possible to achieve nearly flat turns if the craft is designed properly. The principal factors affecting roll stability at speed are

* sidewall geometry
* seal characteristics
* vertical location of the center of gravity.

The forces acting at the center of gravity station of the starboard sidewall in a port turn are shown in Figure 1. The centrifugal force generated acts away from the center of the turn. This force must be counteracted by hydrodynamic forces which are created by yawing the ship into the turn. To an observer aboard the craft, it would appear as if the craft is sideslipping. Wave buildup on the outboard sides of the sidewalls increases the pressure there, while only small pressure changes occur on the inboard side of the opposite sidewall generating a small (negligible) vertical force. The principal force arises from the outboard side of the sidewall. The direction of this force depends on the slope of the deadrise angle. If the resultant force passes above the center of gravity (solid line in Fig. 1) a restoring

moment results, tending to heel the craft into the turn thereby improving its roll stability. If the deadrise angle is chosen to be larger (e.g. 70 deg, shown dashed), the resultant force passes below the center of gravity, resulting in a moment tending to heel the craft out of the turn.

Thus, once the SES geometry and the exact vertical location of the center of gravity are known, an approximate check for stability in a turn can be made.

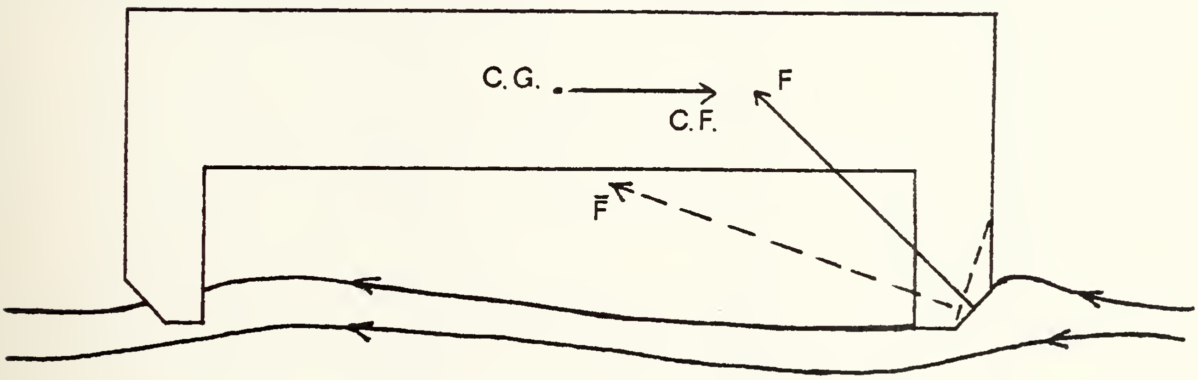


Figure 1 - GENERAL ROLL STABILITY CHECK IN A PORT TURN (C.F. CENTRIFUGAL FORCE, C.G. CENTER OF GRAVITY)

3. XR-3 Sidewall Geometry

From the construction data entered into the sidewall table (subroutine SIDETAB) Figure 2 has been drawn showing the cross sections at several selected stations of the starboard sidewall. Since in most simulation runs (which will be discussed later) draft was less than 7 inches, the deadrise angles for all stations immersing into the water have been calculated by straight line approximation and are given in TABLE V. The stations are counted from bow (station 0) to stern (station 28) and are not equally spaced for station numbers less than 11. The center of gravity has been located experimentally at station 14. The average deadrise angle of all stations listed is 64.3 degrees.

TABLE V

Deadrise angles (deg) for all stations

Straight line approximation for 7'' draft

Station	Deadrise angle	Station	Deadrise angle
5	67.6	17	62.1
6	70.8	18	64.0
7	57.9	19	65.3
8	54.4	20	66.7
9	53.7	21	68.1
10	53.7	22	6.96
11	53.7	23	70.3
12	55.6	24	71.1
13	57.3	25	72.4
14	58.5	26	73.8
15	59.7	27	76.9
16	60.9	28	78.8

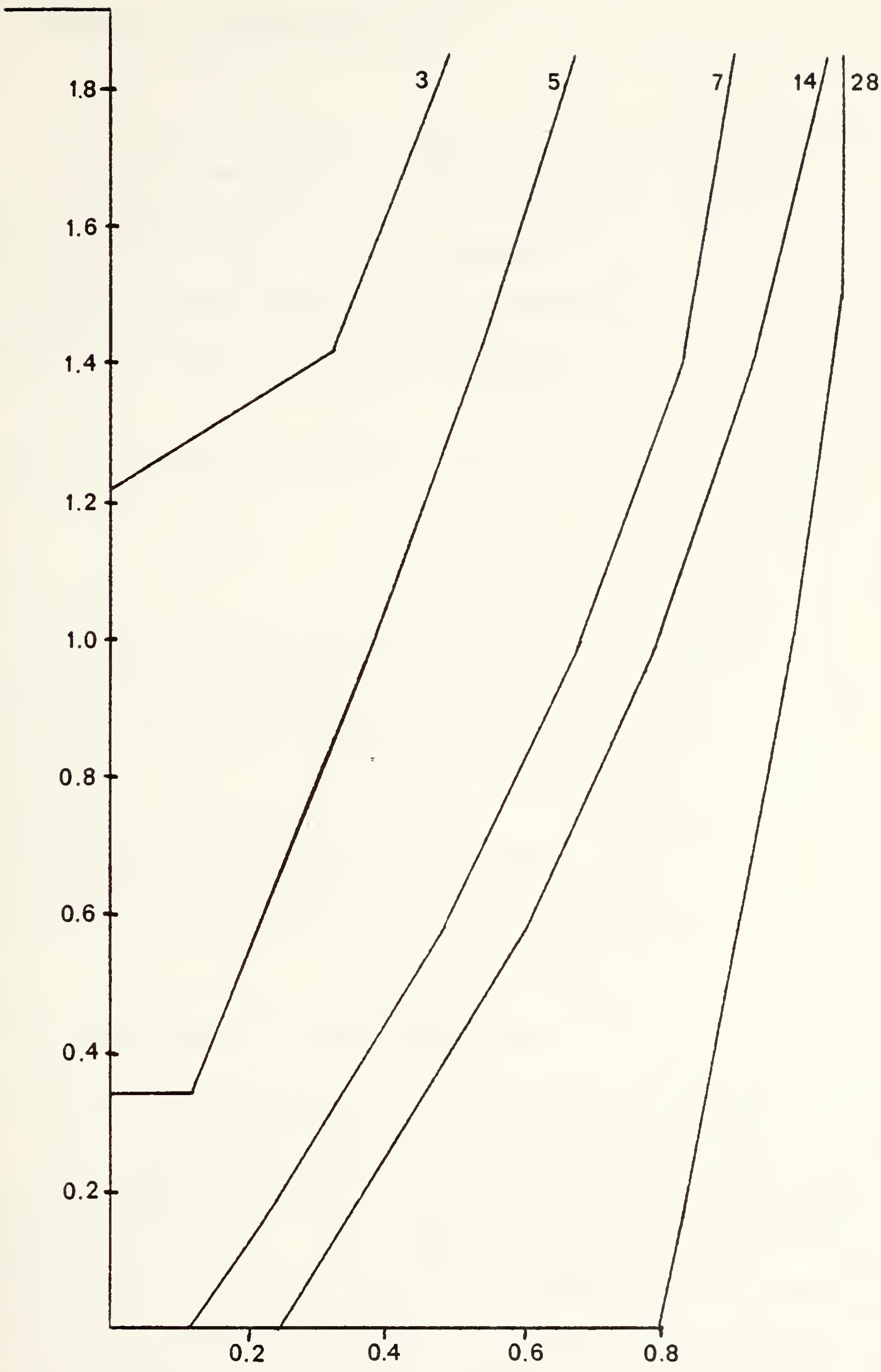


Figure 2 - XR-3 STARBOARD SIDEWALL CROSS SECTIONS
(STATIONS AS INDICATED, UNITS IN FT.)

4. Effect of Deadrise Angle

From the previous discussion the surface effect ship's stability behavior is expected to be sensitive to the sidewalls' deadrise angle. In the XR-3 Loads and Motions Program listed in Ref. 2 the deadrise angle at the transom (78.8 deg) had been used for the computation of the deadrise forces. This calculation was implemented into subroutine SIDEWALL using the following statements:

```
      FYH(J)=-A22S*U*(V+XSS*R-ZS*P)
      •
      •
      CTNDR=0.0
      IF(DSS.LE.0.0) GO TO 22
      CTNDR=(ES-BB(1))/DSS
      IF(THETA.LT.0.0) CTNDR=0.39391
   22 CONTINUE
      FZHOLD(J)=FZH(J)
      FZHDRP(J)=PM1*FYH(J)*CTNDR*PROMO1
      FZH(J)=FZH(J)+FZHDRP(J)
      •
      •
      FK=(FZH(2)-FZH(1))*YSW+FKD-FY*ZS
```

The projection of the lateral force FYH(J) at each sidewall (J=1 for port, J=2 for starboard side) produced the respective component of vertical force FZH, where FZHDRP is the projected force and CTNDR is the cotangent of the deadrise angle. The roll angle had been already taken into account in the computation of DSS (draft at the stern). The factor PROMO1 simply provided a means to arbitrarily change the vertical projected force for studies undertaken in Ref. 2. The factor PM1 introduced the necessary sign change

in the sidewall force computation being dependent on the craft's side (PM1=-1 for port, PM1=+1 for starboard side). The roll moment FK was partly determined from the vertical forces of both sidewalls.

Comparing the deadrise angles given in TABLE V it is seen that the transom deadrise angle of 78.8 degrees is unique and the largest along each sidewall and no reason could be found why just the transom deadrise angle should be used for the vertical force computation. This fact rather came up when Leo and Boncal (Ref. 8) scaled down the simulation program of the 100-B testcraft to create the XR-3 Loads and Motions Program. For the 100-B testcraft the sidewall cross sections are uniformly shaped throughout most of its length. This uniformity does not occur for the XR-3, as shown in Figure 2. Therefore it has been supposed that another deadrise angle which is more representative for all angles existing along the XR-3 sidewalls, e.g. the deadrise angle at the center of gravity location (station 14), could possibly be more appropriate for the vertical force computation. To investigate the effect of this supposition, turn maneuvers in calm sea at 20 knots and various rudder angles have been simulated for both deadrise angles and lateral added mass coefficients.

TABLE VI

Steady State Roll Angle (deg) at 20 kn for various Rudder Angles (deg)

Rudder angle	Deadrise force computation at transom	center of gravity		Experimental testcraft data (Ref.6)
	$C_h=0.4$	$C_h=0.4$	$C_h=0.8$	
5	0.52	0.32	0.29	0.09
9	1.07	0.78	0.72	0.28
12	1.50	1.15	1.11	0.58
15	1.98	1.53	unstable	1.36

Table VI shows the steady state values for the roll angle which are compared with those measured experimentally in 1974 and documented in Ref. 6. Since the XR-3 Loads and Motions Program under investigation represents the XR-3 craft configuration as it existed in 1974, Ref. 6 may serve to check whether the results produced by certain changes in the simulation program are favorable or not. It is not anticipated to exactly match the results obtained from the simulated runs to the measured values since for the testcraft data the following precisions for the measuring devices are stated in Ref. 6 : pitch and roll angle ±0.5°, rudder angle ±1.0° and speed ±1 kn. From TABLE VI it is obvious that the steady state values for roll angle using C_h=0.4 as the lateral added mass coefficient and the center of gravity deadrise angle for the vertical force computation are closer by 25 to 40 % to the measured angles than are the corresponding roll angles considering the transom deadrise angle.

Using the center of gravity deadrise angle and the lateral added mass coefficient C_h=0.8 as suggested in Ref. 3, the agreement in steady state roll angles could be improved by another 3 to 10 % for rudder angles up to 12 degrees. This improvement has also been reported in Ref. 3. Comparing the roll angle responses for turns generated by a 12 degrees rudder angle to port with C_h=0.4 (plots 21 and 22) and C_h=0.8 (plots 23 and 24) it is found that the smaller lateral added mass coefficient generates a little higher peak roll angle (1.47°) than does the larger coefficient (1.27°). Both responses show the same number of oscillations (eleven cycles) until they die out. The larger lateral added mass coefficient generates a small negative

roll angle shortly after the port rudder motion has been introduced. However, for a 15 degrees port rudder angle the simulation program showed an unstable response with increasing amplitudes of oscillation for pitch and roll angle (see plots 17 and 18). From this the lateral added mass coefficient being 0.8 does not seem to be appropriate for the XR-3 simulation if both sidewalls are considered for the vertical deadrise force computation. The effect of using both lateral added mass coefficients will be considered again in Sections III.D and E.

From TABLE VII it can be seen that the roll moments contributed by the bow seal (FKBS), plenum pressure (ABPB*PHI*Z), rudder (FKRUD) and sidewalls (FKSW) change the most. Comparing the effect due to the change from transom to center of gravity deadrise angle it is found that

- bow seal inward effect decreases

- plenum pressure outward effect decreases

- rudder inward effect decreases

- sidewall outward effect increases

= outward roll angle decreases.

The time histories for simulated turn maneuvers with 15 degrees port rudder angle using center of gravity and transom deadrise angle (TABLE VII) are shown in Appendix A as plots 13-16 and 9-12, respectively. Comparing these plots the effect of the change from transom to center of gravity deadrise angle and C_h=0.4 can be observed as

- pitch angle response being more damped

- roll angle response being more damped

- pitch and roll rate responses being more damped and having smaller peak values.

TABLE VII

Steady State Values for selected Deadrise Angles

20 kn Turn, calm Sea, 15 deg port rudder angle

Deadrise Angle	Transom	C. of G.	arbitrarily	chosen
(degrees)	78.8	58.5	31.6	28.7
Pitch angle (deg)	0.52	0.45	0.52	0.64**
Roll angle (deg)	1.98	1.53	0.31*	- 0.33*
Draft (in)	5.94	5.81	6.07	6.52
Speed (kn)	19.27	19.37	19.1	18.7
FYSW	-824.0	-821.9	-810.0	-801.0
FYRUD	40.0	32.7	39.5	55.8
FYAED	- 19.5	- 20.0	- 19.1	- 17.6
R*V*AM	803.5	809.2	789.6	762.8
FKBS	-386.3	-336.4	- 68.4	71.6
FKSS	- 3.6	- 2.7	- 0.5	0.5
FKSW	202.0	212.1	175.0	184.0
FKRUD	-110.0	- 89.9	-108.4	-153.0
FKAED	- 53.5	- 56.0	- 52.4	- 46.2
FKP	0.19	0.14	0.03	- 0.03
ABPB*PHI*Z	351.9	273.5	54.6	- 57.2
FYH (P/S)	-39/-147	-45/-126	-78/-95	-107/-88
FYD	-637.8	-651.4	-637.3	-607.0

Note : * = still decreasing

** = still increasing, not quite steady state

The reason for the sidewall roll moment and thereby the net roll effect not changing more pronounced (TABLE VII) is that not cnly the lateral force FYH must be considered in order to determine the force F effecting roll stability (Sect. III.B.2, Fig. 1) but also the lateral drag force FYD has to be taken into account. Considering the XR-3 geometry using the center of gravity deadrise angle, as it is shown in solid lines in Fig. 3, the lateral force FYH can be seen to generate the vertical projected force FZHDRP and the force F, which is directed well above the center of gravity. But since FYD has to be added vectorially to the force F and its strength being several times larger than FYH (TABLE VII) the new resultant force F' determining the craft's roll behavior is directed well below the center of gravity (although F being directed above it). Thereby an outward roll angle is generated.

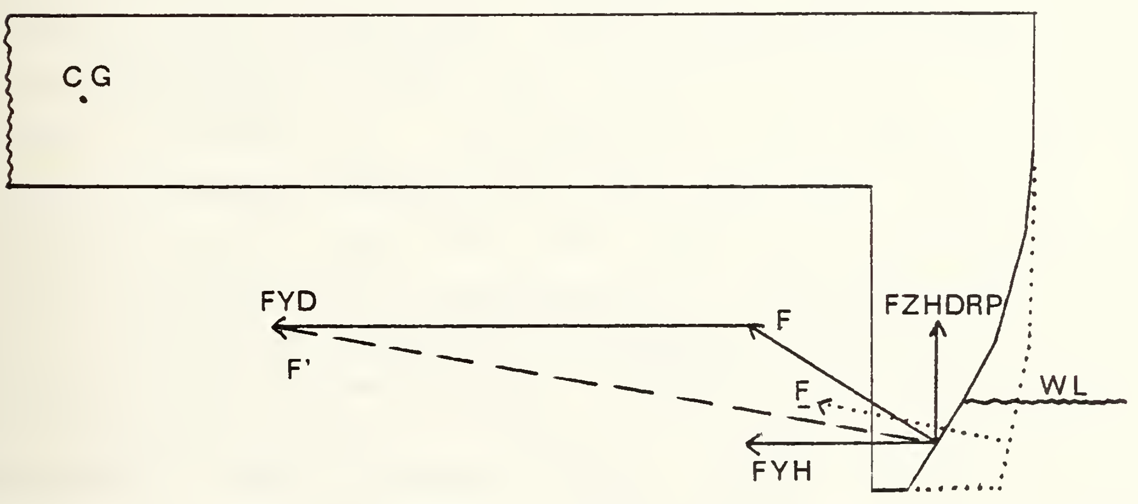


Figure 3 - DEADRISE AND DRAG FORCES IN A PORT TURN (CG= CENTER OF GRAVITY, WL= WATER LINE)

Also from Fig. 3 the effect of considering the center of gravity versus the transom deadrise angle on the force generating the inward or outward roll moment can be seen. The center of gravity deadrise angle and its corresponding forces are shown in solid or dashed lines with F being directed above the center of gravity. The transom deadrise angle, shown in dotted lines, generates a force F being directed below the center of gravity producing an outward roll moment which gets reinforced by adding vectorially FYD. From this the general stability check yields a smaller outward roll moment and angle using the center of gravity versus the transom deadrise angle. This is in agreement with the results given in TABLE VI.

Next, some simulation runs with arbitrary deadrise angles chosen such that small positive and negative steady state roll angles result are presented in order to, first, find out which deadrise angle would generate the moments necessary to simulate flat turns, and, second, verify the trend of the change in the respective moments which has been observed for the change from transom to center of gravity deadrise angle in TABLE VII. The value of the lateral added mass coefficient in these runs was 0.4 as it was in all runs listed in TABLE VII. Considering the roll moments over the range of deadrise angles from 78.8 to 28.7 degrees, the moments due to the bow seal, stern seal, propulsion and plenum pressure change consistantly in magnitude while those due to sidewalls, rudder and aerodynamics reach some extreme value and then increase again. Regarding the steady state roll angles listed in TABLE VII, it can be seen that the arbitrary chosen deadrise angles happen to be nearly symmetric about the deadrise angle that would generate zero roll angle (flat turn) under these simulation conditions. Keeping this symmetry in mind one finds that the values of the roll moments due to bow seal (FKBS), stern seal (FKSS), propulsion (FKP) and plenum pressure (ABPB*PHI*Z) are also

symmetric with respect to zero moments. For propulsion and plenum pressure the sign of the moments are identical to that of the roll angle while for bow and stern seal moments the signs are reverse. From the results given in TABLE VII with positive steady state roll angles Figure 4 has been drawn where the dotted line represents the craft's initial state, the dashed line represents the craft's steady state considering the transom deadrise angle and the solid line represents the craft's steady state (smaller roll angle) considering the center of gravity deadrise angle for the vertical force calculation. Same markings apply to the moment vectors shown from which their change in magnitude for both deadrise angles can be seen.

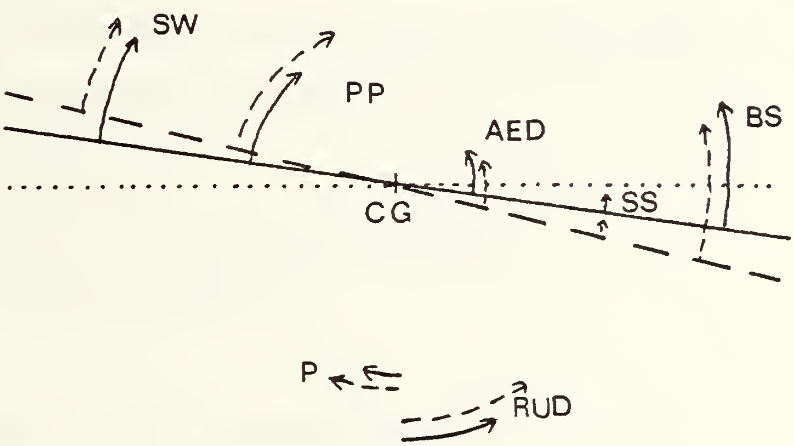


Figure 4 - ROLL MOMENTS IN A PORT TURN
(ROLL MOMENTS AND ANGLE NOT TO SCALE)

Legend: AED Aerodynamic — CG Center of gravity
BS Bowseal — PP Plenum pressure
SS Sternseal — SW Sidewalls
RUD Rudder — P Propulsion
Deadrise angle: - - - Transom
——— Center of gravity

Since the simulation run with the center of gravity deadrise angle being used for the vertical force computation gave results that were more favorable (better damped time histories and steady state values closer to those measured experimentally) this change in vertical force computation was implemented into the XR-3 Loads and Motion Program. Starting with the deadrise angle given in Table V for draft up to seven inches, again straight line approximations for the effective deadrise angle at the center of gravity location (station 14) for larger drafts have been performed resulting in an almost linear relationship. This part of subroutine SIDEWALL is now valid for any draft and contains the following statements which have been used in this form for all simulation runs to follow in this study:

```
DDRANG=0.0
IF (DS.GT.0.5833) DDRANG=(DS-0.5833)*0.0629
DRANG=1.021+DDRANG-PM1*PHI
CTNDR=COTAN(DRANG)
FZHOLD(J)=FZH(J)
FZHDRP(J)=PM1*FYH(J)*CTNDR*PROMO1
FZH(J)=FZH(J)+FZHDRP(J)
•
•
FK=(FZH(2)-FZH(1))*YSW+FKD-FY*ZS
```

It should be noted that vertical projected forces from <u>both</u> sidewalls are used in computing the roll moments in the XR-3 Loads and Motions Program. Section III.E of this thesis will be concerned with the effect of changing the simulation program to consider the deadrise projected force only from the outward sidewall in a turn maneuver as it is discussed in Sect. III.B.2 .

C. CROSS-FLOW DRAG

In the preceding section the lateral force FYD which is due to cross-flow drag has been found to be rather large compared to FYH, thereby changing the direction of the resultant force significantly. FYD is computed in subroutine SIDEWALL by summing the contributions DF of all stations:

```
DF(I,J) = -HRHO*CDSW*VREL*ABS(VREL)*DSWAV(I,J)
```

where DF(I,J) is the lateral drag contributed by the j-th element of each (i-th) sidewall

HRHO is RHO/2.

VREL is relative velocity

DELX is the incremental distance used for the wetted draft calculation along each sidewall

DSWAV is the average wetted draft over one incremental distance

CDSW is the cross-flow drag coefficient for one sidewall .

The cross-flow drag coefficient being used in the present XR-3 Loads and Motions Program is the value corresponding to that for flow normal to a long flat plate being CDSW=1.28 . Ref. 3 points out that an investigation of cross-flow drag forces and coefficients (before the vertical added mass A33 had been reformulated as discussed in Sect. III.A.1) showed better agreement between theoretical and experimental results if CDSW=2.0, representing the normal drag coefficient for a sharp flat plate, had been used instead. After the reformulation of A33 the agreement between modified theory and experiment had very much improved, so

that the former drag coefficient could be used again. Since in this thesis work the change in A33s did not effect the roll behavior significantly (TABLE IV), some turn maneuvers at 20 kn and 15 degrees rudder angle have been simulated for various drag coefficients in order to investigate which CDSW would better match simulated and experimental steady state roll angle. From TABLE VII a decrease in roll angle and roll moment is desireable and therefore the cross-flow drag force FYD should be decreased via reducing CDSW. The steady state values are shown in TABLE VIII with the lateral added mass coefficient being unchanged $C_h = 0.4$.

TABLE VIII

Steady state conditions for various CDSW

20 kn turn, 15 deg port rudder angle

CDSW	1.28	1.16	1.0	0.7
Pitch angle	0.43	0.43	0.44	0.46
Roll angle	1.55	1.48	1.38	1.14
Draft	5.78	5.80	5.83	5.91
Speed	19.39	19.36	19.31	19.19
FKBS	-343.0	-330.5	-308.1	-252.8
FKSS	- 2.7	- 2.6	- 2.4	- 2.0
FKSW	207.8	175.0	127.8	40.0
FKRUD	- 82.2	- 47.9	- 2.3	80.4
FKAED	- 56.6	- 58.7	- 61.6	- 67.6
FKP	0.14	0.14	0.13	0.11
ABPB*PHI*Z	276.4	264.6	246.5	201.9
FYH (P,S)	-43/-125	-45/-125	-48/-124	-57/-121
FYD	-654.9	-616.9	-561.0	-436.0

Comparison with Ref. 6 (Table VI) shows close agreement in roll angle (1.36°) for the run with CDSW=1.0 . But these

trial runs have been executed with arbitrary smaller drag coefficients because an increase in drag coefficient (e.g. CDSW=2.0 for sharp flat plate as in Ref. 3) would have enlarged the disagreement between simulated and experimental data. Also, from plot 29 for CDSW=1.28 and plot 31 for CDSW=1.16 it is seen that a smaller drag coefficient results in more damping in the roll response, in this case six versus nine cycles of distinguishable oscillations. Since the choice of CDSW=1.0 cannot be declared to be appropriate for the actual shape of the XR-3 sidewalls it will not be considered any further in this study. CDSW=1.16 generated a 4 % change (about 15 % is desired) toward the experimentally measured roll angle and its effect will be investigated together with the present cross-flow drag coefficient CDSW=1.28 in the studies to follow.

Shown below in Figure 5 is the dependence of steady state roll angle in turns generated by a 15 degrees rudder angle to port at 20 kn on the cross-flow drag coefficients used in the simulation runs (TABLE VIII).

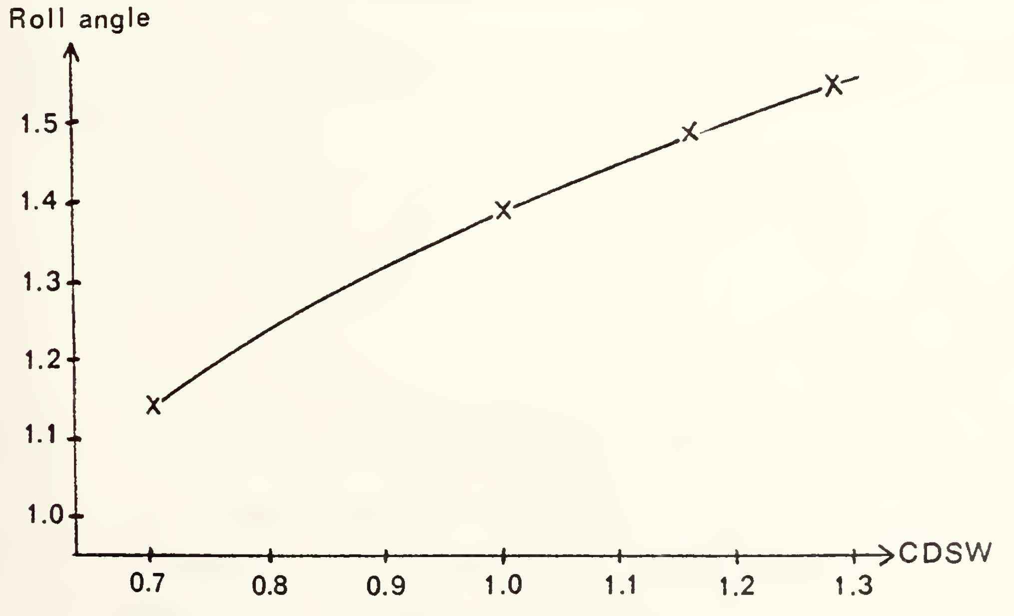


Figure 5 - S.S. ROLL ANGLE VERSUS CDSW

D. THRUST MAPPING

In turn maneuvers as they have been discussed in the preceding sections another important point to be considered is the change in thrust on both engines. Since the engines mounted on the XR-3 provide constant power for a given throttle setting, the actual thrust delivered during a turn maneuver may vary even though the throttle remains fixed. In all simulation runs shown in this thesis until now constant thrust has been used. In Ref. 6 experimentally measured reduction in thrust is given for turn maneuvers at 20 kn and various rudder angles. From this and Ref. 7 providing more detailed information the thrust-rudder dependence was as listed below.

TABLE IX
Reduction in thrust for various rudder angles in turn maneuvers at 20 kn

Rudder angle (deg)	total reduction in thrust (Ref. 6) (%)
5	- 2.8
9	- 3.3
12	- 4.3

TABLE IX has been used for thrust mapping (Block 16 of the data input) in the simulation runs. Due to unavailability of more precise data it has been assumed that the total reduction in thrust is contributed from both engines in equal amounts. But this may not be quite true, since due to the craft's roll angle a difference in immersion depth for both engines could result in unequal

changes in thrust. TABLE X shows the steady state values of these simulations considering two cross-flow drag coefficients, deadrise force contributions from both sidewalls computed at the center of gravity as well as both lateral added mass coefficients C_h=0.4 (0.8).

TABLE X

Steady state conditions using thrust mapping in 20 kn turns at various rudder angles

Rudder angle (deg)	Roll angle (deg) simulation	Roll angle (deg) Ref. 6	Speed (kn) simulation	Speed (kn) Ref. 6
CDSW=1.28				
5	0.30(0.25)	0.09	19.3(19.2)	19.8
9	0.71(0.61)	0.28	18.9(19.0)	19.5
12	0.99(0.89)	0.58	18.5(18.6)	19.2
CDSW=1.16				
5	0.28(0.23)	0.09	19.2(19.2)	19.8
9	0.67(0.57)	0.28	18.9(19.0)	19.5
12	0.94(0.84)	0.58	18.4(18.6)	19.2

Comparing the steady state roll angles obtained if thrust mapping is used with those listed in TABLE VI (no thrust mapping, deadrise force computation at the center of gravity), a change in roll angle by 6 to 14 % for C_h=0.4 and by 14 to 20 % for C_h=0.8 toward the measured angle can be observed. The steady state roll angles found in the simulation runs still differ from the roll angles given in Ref. 6 by a factor of about two and three but can be expected to be a little closer to these if proper thrust mapping, i.e. different maps for port and starboard engine, is used. By this also the steady state velocities which

differ by about 2.5 % can be expected to come in better agreement, i.e. to increase for smaller roll angles.

Regarding the roll angle time responses for simulation runs using both lateral added mass coefficients (0.4 and 0.8) and 12 degrees rudder angle the following characteristics have been found: the runs using thrust mapping (Table X, plot 33(35)) show almost the same transient behavior as do the runs without thrust mapping (Table VI, plot 21(23)) with about ten cycles of oscillation before the transients die out. But the runs using thrust mapping need quite a long time (t>45 sec) before they reach the steady state roll angle.

The effect of using a larger lateral added mass coefficient (0.8) can be observed in plot 35. Comparing this with plot 33, the roll angle response in plot 35 shows a smaller peak roll angle (1.25^{o} versus 1.47^{o}) and the transients have smaller amplitudes. But both die out after ten cycles. This effect has already been noted in Section III.B.4.

Investigating the effect of changing the coefficient CDSW=1.28 to 1.16 by comparison of the roll responses shown in plots 33 and 37 or 35 and 39, a significant damping effect as has been found previously in Section III.C can not be observed here.

E. DEADRISE FORCE OF OUTWARD SIDEWALL

This part of the investigation on how to effect the roll behavior of the testcraft simulation is again concerned with the deadrise angle.

In the present XR-3 Loads and Motions Program deadrise forces for both sidewalls are computed with the deadrise angle appropriately corrected by the roll angle for port and starboard sidewalls. The idea behind this, e.g. in a port turn, is to consider a pressure buildup (large FYH(S)) on the outboard side of the starboard sidewall and a reduction in pressure on the outboard side of the port sidewall (small FYH(P)). Thereby an upward vertical force FZHDRP (with negative sign) is obtained for starboard side, while a downward vertical force (positive sign) is computed for port side. Both vertical forces are then added to the buoyancy force of their side. The forces obtained by this approach are shown in Figure 6.

In Ref. 4, however, a different philosophy in regarding the acting forces is presented. As discussed in Section III.B.2 an approximate check on the craft's roll stability can be made if the SES geometry and the vertical location of its center of gravity are known (Fig. 1). In a port turn the principal force effecting the roll behavior arises from the <u>outboard</u> side of the starboard sidewall (relative high pressure on the structure there due to wave buildup) while there is only a small force (due to small pressure change) on the <u>inboard</u> side of the port sidewall contributing a roll moment only if there exists a roll angle. Now both vertical forces are directed upward. This approach and the resulting forces are shown in Figure 7.

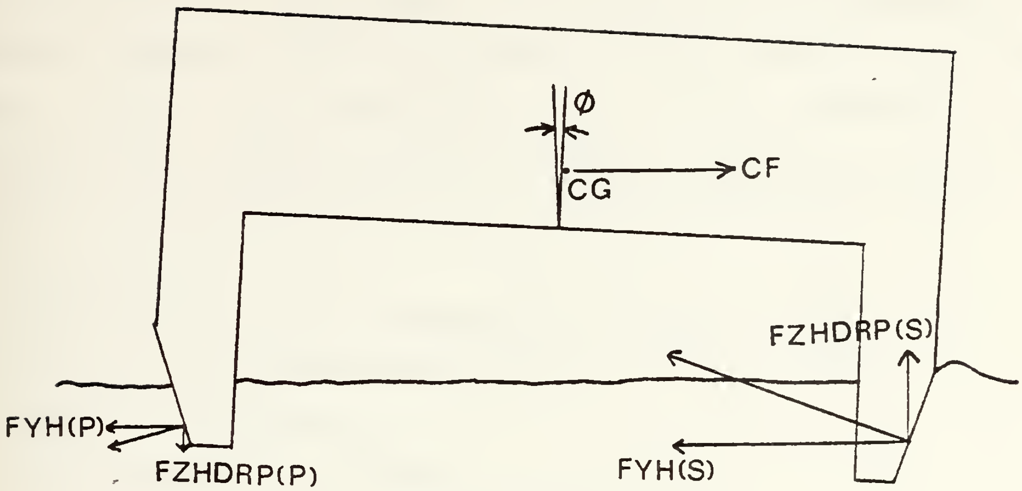


Figure 6 - ACTING DEADRISE FORCES (TWO SIDEWALLS)

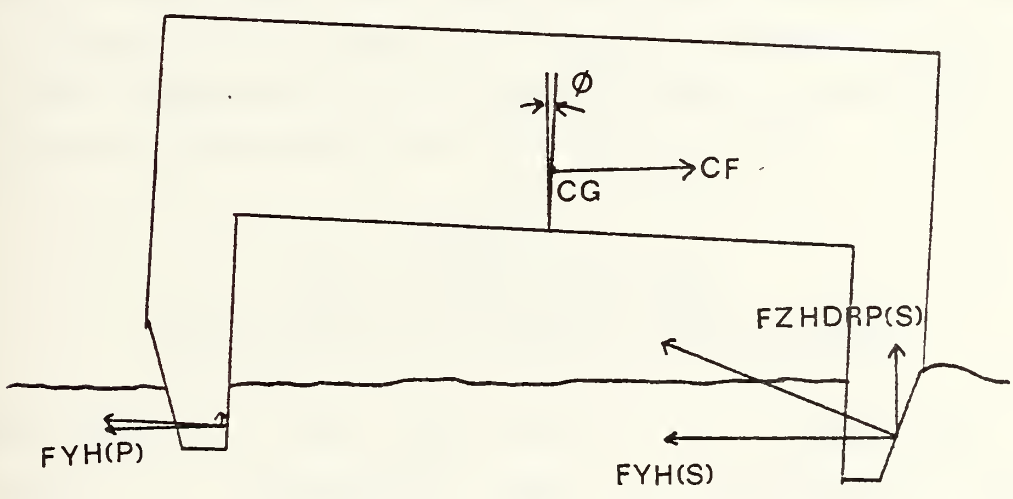


Figure 7 - ACTING DEADRISE FORCES (ONE SIDEWALL)

Note : Since the vertical force contributed by the inboard sidewall is rather small, as shown above, it can be neglected in the roll stability check (Sect. III.B.2).

To investigate the effect of this interpretation of the acting forces two statements controlling the computation of deadrise forces via the sign of the rudder angle RUDANG (port rudder is positive) and the sidewall under investigation (PM1=-1 for port side) have been added to the computation procedure for the vertical projected force :

```
DDRANG=0.0
IF (DS.GT.0.5833) DDRANG=(DS-0.5833)*0.0629
DRANG=1.021+DDRANG-PM1*PHI
CTNDR=COTAN(DRANG)
RUDSIG=SIGN(1.,RUDANG)
IF(RUDSIG.NE.PM1) CTNDR=PM1*TAN(PHI)
FZHOLD(J)=FZH(J)
FZHDRP(J)=PM1*FYH(J)*CTNDR*PROMO1
FZH(J)=FZH(J)+FZHDRP(J)
```

The steady state values for simulated turn maneuvers using thrust mapping and center of gravity deadrise angle are shown below considering two cross-flow drag coefficients and both lateral added mass coefficients C_h=0.4(0.8).

TABLE XI

Steady state conditions

in 20 kn turns at various rudder angles

Rudder angle (deg)	Roll angle (deg) simulation	Roll angle (deg) Ref. 6	Speed (kn) simulation	Speed (kn) Ref. 6
CDSW=1.28				
5	0.43(0.52)	0.09	19.4(19.5)	19.8
9	0.90(1.00)	0.28	19.1(19.4)	19.5
12	1.22(1.34)	0.61	18.7(19.0)	19.2
CDSW=1.16				
5	0.41(0.51)	0.09	19.3(19.5)	19.8
9	0.87(0.98)	0.28	19.1(19.3)	19.5
12	1.17(1.30)	0.61	18.6(19.0)	19.2

Comparing the steady state values for simulated runs in tables X and XI , the effect of using only the outward sidewall for the deadrise force computation can be observed to give less favorable (little larger) steady state roll angles but more favorable (larger) steady state velocities. This is exactly what has been expected since, as shown in Figures 6 and 7, if deadrise force contributions from both sidewalls are used, the deadrise force from the port sidewall will reinforce the one from the starboard sidewall toward a less outward roll moment (Fig. 6) while applying the philosophy depicted in Fig. 7 the vertical force from the port sidewall counteracts the starboard deadrise force.

Regarding the roll angle responses shown in Appendix A for 12 degrees rudder angle with CDSW=1.28 (plots 41 and 43) and CDSW=1.16 (plots 45 and 47) and comparing these with the corresponding ones from the previous section (plot 33, 35 and 37, 39) the change in the vertical force computation considering the outward sidewall only is seen to result in about 8 versus 10 cycles of transient oscillations with less amplitude. Using C_h=0.8 (plots 43 and 47) has a quite significant damping effect and makes the roll angle response more resemble a step, which is in accordance with the experience gained by Ref. 7. Also, comparing these plots with plots 35 and 39, the negative roll angle occurring at the moment when the rudder has been introduced does not show up any more.

F. VERTICAL LOCATION OF CENTER OF GRAVITY

In Section III.B.2 it was discussed how to check for the testcraft's roll bahavior in a turn provided the SES geometry and the location of the center of gravity are known. This section will be concerned with the effect of different vertical locations of the center of gravity on the simulated XR-3 roll behavior

From experimental measurement the location of the center of gravity of the XR-3 has been determined to be 10.05 ft forward of the transom and Leo and Boncal established the vertical location at 2.54 ft above the keel on the longitudinal center line of the craft. As modifications to the testcraft were introduced (e.g. engines and seals) the horizontal location of the center of gravity was again established experimentally. No such changes were made on the vertical location. In order to investigate the sensitivity of the steady state roll angle to vertical locations of the center of gravity, reductions in height (in accordance with the stability check geometry depicted in Figure 1) in increments of 0.1 ft were entered into the Loads and Motion Program.

Simulation runs with constant thrust and initial speed of 20 kn introducing a 15 degrees port rudder angle, deadrise force contributions from both sidewalls computed at the center of gravity, the sidewall drag coefficient CDSW=1.28 and the lateral added mass coefficient being 0.4 were executed and the results are shown in Table XII. From the listed data it follows that with a lower vertical location of the center of gravity a tendency toward an inward roll angle (here actually a smaller outward roll

angle) can be achieved. As shown, a decrease in vertical distance by 0.1 ft resulted in about 0.1 degree decrease for both peak and steady state roll angle (almost linearly related). From the corresponding plots as indicated in Table XII a roll damping effect due to the relocation of the center of gravity can hardly be recognized. The number of cycles of transient oscillations and the steady state speed were about the same for all runs listed in Table XII.

TABLE XII

Roll conditions in 20 kn turn with constant thrust and 15 degrees port rudder angle

	vertical location of CG				experimental
	2.54	2.44	2.34	2.24	testcraft data
steady state roll angle	1.55	1.43	1.32	1.22	1.36
peak roll angle	1.67	1.53	1.46	1.35	
peak roll rate	2.13	2.07	1.98	1.91	
cycles of transients	8	8	8	8	
refer to plots	13-14	49-50	51-52	53-54	
steady state speed	19.4	19.3	19.3	19.3	18.7

Table XIII shows the effect of changing the vertical location of the center of gravity for simulation runs at 20 kn with 12 degrees port rudder angle and thrust mapping applied, deadrise force computation for both sidewalls at the center of gravity and the coefficients being 0.4 for the lateral added mass and CDSW=1.28 for the sidewall drag. These conditions were similar to those used in Table X.

From Table XIII the effect of reducing the vertical location of the center of gravity in 0.1 ft increments over a reasonable range can be observed to also result in linear reductions in maximum and steady state roll angle for the case if thrust mapping is used. Nonlinear reductions appear for the peak roll rate. The number of cycles during the transient period (ten) is again not effected by the vertical relocation of the center of gravity. Regarding the corresponding plots a very slight damping effect can be observed for reduced vertical locations. The results given in Table XIII are graphically represented in Figure 8 .

TABLE XIII

Roll conditions in 20 kn turn with thrust mapping and 12 degrees port rudder angle

	vertical location of CG 2.54	2.44	2.34	2.24	experimental testcraft data
steady state roll angle	0.99	0.91	0.84	0.77	0.58
peak roll angle	1.47	1.36	1.25	1.16	
peak roll rate	2.14	1.92	1.74	1.58	
cycles of transients	10	10	10	10	
refer to plots	33-34	55-56	57-58	59-60	
steady state speed	18.5	18.4	18.4	18.4	19.2

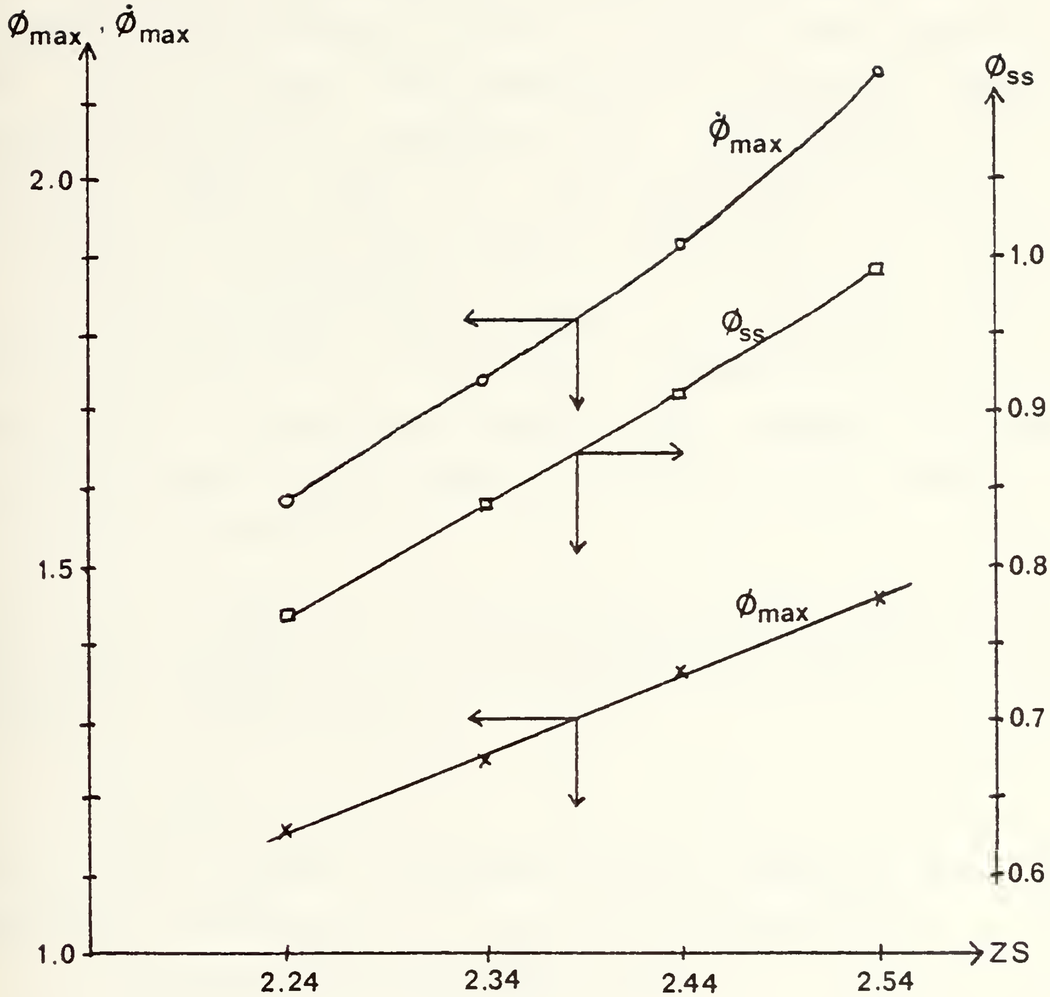


Figure 8 - ROLL CONDITIONS VERSUS VERTICAL LOCATION OF CENTER OF GRAVITY (TABLE XIII)

G. ROLL DAMPING DUE TO VERTICAL WAVE GENERATION

One part of subroutine SIDEWALL is concerned with the roll damping effect which is due to vertical wave generation during a roll motion. The computation of the roll damping term was developed by Oceanics Inc. and added to the program by Menzel [Ref. 2]. The principles used in the development of this addition were not provided by Oceanics Inc., however, the apparent idea is to reduce the computed roll moment FK by some value which is dependent on the craft's roll rate and its draft, thereby on the vertical added mass A33. During the study of the effect of these additional terms a discrepancy was noted in the dimensions used in the calculations.

The roll moment FK is calculated by the equation given in SDWL1950 and considering the expressions leading to this statement it is found that

dim [FK] = lb . ft

which is the correct dimension for a moment vector. Now considering the dimension of the roll damping term

dim [PROMO2*YSW*YSW*BC2*P/PI]

which is subtracted from FK (SDWL2200) it is found

PRCMO2 and PI are dimensionless
dim [YSW] = ft
dim [P] = rad/sec
dim [BC2] = dim [AC2]
= dim [FC2 * length]
= dim [F2 * cos(x) * length]
= dim [A33 * length]

$= \dim [RHO * B * B * length]$

$= (lb \cdot sec^2 / ft^4) \cdot ft \cdot ft \cdot ft$.

So for the roll damping term

$\dim [YSW * YSW * P * BC2]$

$= ft^2 \cdot (rad/sec) \cdot (lb \cdot sec^2/ft^4) \cdot ft^3$

$= lb \cdot ft \cdot sec$

which is not the correct dimension for a moment expression. Assuming that only the given terms may be involved in the roll damping calculation, it is possible to come up with the proper dimension if the roll rate P were squared but keeping its sign, thus getting

roll damping term = PROMO2*YSW*YSW*BC2*P*ABS(P)/PI .

Also the vertical added mass should be associated with some 'velocity squared' - expression which is absent in the original version of this part of the program but could be generated by squaring the roll rate P. The effect of the modified expression will be an increase in the damping effect for roll rates P>1.0 which exist only in the initial phase of the turn maneuver (maximum roll rate in all simulation runs was about 2.0) . But for most of the run length P is less than unity and the supposed modification will decrease the damping effect especially when approaching steady state (P=0.0) .

The PROMO2 - term provides a means to arbitrarily set a roll damping factor which, as stated in Reference 2, has been found from experiments to be 16.0 . Until now PROMO2=1.0 has been used in this thesis work. So the effect of changing it to the experimental value is investigated next. In the runs to be discussed turn maneuvers at 20 kn with a 12 degrees port rudder angle have been simulated with deadrise forces being computed at the center of gravity, using the experimental damping factor PROMO2=16.0 and the

coefficients CDSW=1.28 for the sidewall drag and C_h=0.4 for the lateral added mass.

1. Thrust is held constant with deadrise force contributions from both sidewalls

Comparing the obtained plots 61-62 with plots 21-22 (PROMO2=1.0) only a slight damping effect on roll angle response can be observed (peak roll angle 1.45° versus 1.47°), but the number of transient oscillations decreases from eleven to nine. The peak roll rate decreased from 2.14 to 2.10 for PROMO2=16.0 and the damping effect is more pronounced in the roll rate time history.

2. Thrust is mapped with deadrise force contributions from both sidewalls

Comparing the plots 63-64 with the corresponding ones (33-34) for PROMO2=1.0 , again only a slight damping effect can be noticed. The peak roll angle is again reduced from 1.47 to 1.45° and the number of cycles of transient oscillations is uneffected.

If the damping term is changed to include the P*ABS(P) expression (plots 65-66) there result eleven versus nine cycles of transient oscillations with little higher amplitudes (peak roll angle is again 1.47° as it was for PROMO2=1.0) . The roll rate time history also shows little larger amplitudes (peak roll rate is 2.14 versus 2.10) .

3. Thrust is mapped with deadrise force contribution from the outward sidewall only and lateral added mass coefficient C_h=0.8

Comparing these plots (67-68) for PROMO2=16.0 with plots 43-44 where PROMO2=1.0 again only a slight damping effect in roll angle response can be noticed with the number of

transient oscillations being uneffected. Using the P*ABS(P) term the slight damping effect shown in plot 67 is cancelled as shown in plot 69.

The above observations show that the experimentally determined roll damping factor PROMO2=16.0 has only a negligible damping effect. Considering the roll damping term again as it was added to the present XR-3 Loads and Motions Program in 1974, there was a 1/PI - factor which actually cancelled the PI - factor contained in the former expression for the vertical added mass A33S (Section III.A). Since the PI - factor already has been eliminated by correcting the A33S - expression, there is no further need to cancel it in the damping term by the 1/PI - term which therefore also could be eliminated. This change is expected to cause an increase in sidewall roll damping by a factor of PI and has been investigated by an additional run.

4. Thrust is mapped with deadrise force contribution from the outward sidewall only, roll damping term being

   16.0*YSW*YSW*BC2*P

   and lateral added mass coefficient C_h=0.8

From plots 71-72 again only a slight damping effect versus plots 67-68 can be noticed.

The investigation described in this section shows that the roll damping due to vertical wave generation as included in subroutine SIDEWALL is not very effective even if the factor PROMO2 in the damping term is increased from 16.0 to 50.0 . There also is a lack in matching dimensions (statement SDWL2200).

IV. PROPULSION AND RUDDER SUBROUTINES

In all simulation runs executed during this study the XR-3 Loads and Motions Program as given in Ref. 2 has been used except for the modifications mentioned in this work. This simulation program contains Forbes' version [Ref. 9] of 'SUBROUTINE PROP' which included some revisions of the original version given by Leo and Boncal [Ref. 8]. Since in TABLE VII (Section III.B.4) the roll moment contributed by the propulsion system (FKP) is rather small (0.1 to 0.2) an additional run using Leo and Boncal's version has been executed under the conditions as stated for TABLE VII (center of gravity deadrise angle). The steady state values are shown below (in parantheses are the values obtained using Forbes' version) :

pitch angle	0.44(0.45)	draft	5.73(5.81)
roll angle	1.67(1.53)	speed	19.39(19.37)
FYSW	-909.4(-821.9)	FYRUD	- 54.7(32.7)
FYAED	- 21.3(- 20.0)	R*V*AM	888.4(809.2)
FYP	97.0(0.0)		
FKBS	-348.0(-336.4)	FKSS	- 3.0(- 2.7)
FKSW	269.9(212.1)	FKRUD	150.3(- 89.9)
FKAED	- 63.5(- 56.0)	FKP	-305.2(0.14)
ABPB*PHI*Z	299.5(273.5)		
FYD	-729.2(-651.4)	FYH (P/S)	-43/-137(-45/-126)

Regarding these values drastic differences are found for FYP and FYRUD as well as for FKP and FKRUD, though the steady state values for pitch and roll angle, draft and speed are close to those obtained using Forbes' version. The pitch and roll angle responses are given in plots 25-28. Comparing these with the corresponding ones using Forbes' version (plots 13-16) it is seen that Leo and Boncal's version generates more oscillatory roll and pitch angle responses. Therefore a review of subroutine PROP especially the computation of the respective forces and moments has been carried out and are discussed below.

The review resulted in force and moment equations which are identical to those given by Leo and Boncal [Ref. 8]. Another point that supports the supposition to use this version of subroutine PROP is the fact that it provides a reasonable roll moment due to the propulsion system (Forbes' version provides almost zero roll moment). In order to test the effect of changing subroutine PROP to its original form, simulation runs 1. and 2. from the preceding section have been repeated and their time histories for the roll behavior are shown in plots 73-74 and 75-76, respectively. Comparing these with the corresponding ones using Forbes' version of subroutine PROP, plots 61-62 and 63-64, it is observed that the steady state and peak roll angles are larger by about 7 % and the number of transient oscillations is uneffected by this change.

Next a review of subroutine RUDDER has been carried out in order to investigate the cause of the change in sign for FYRUD and FKRUD depending on the propulsion subroutine used (Forbes' or Leo and Boncal's version) although identical RUDDER-subroutines have been used in both cases. The important equations to be considered are :

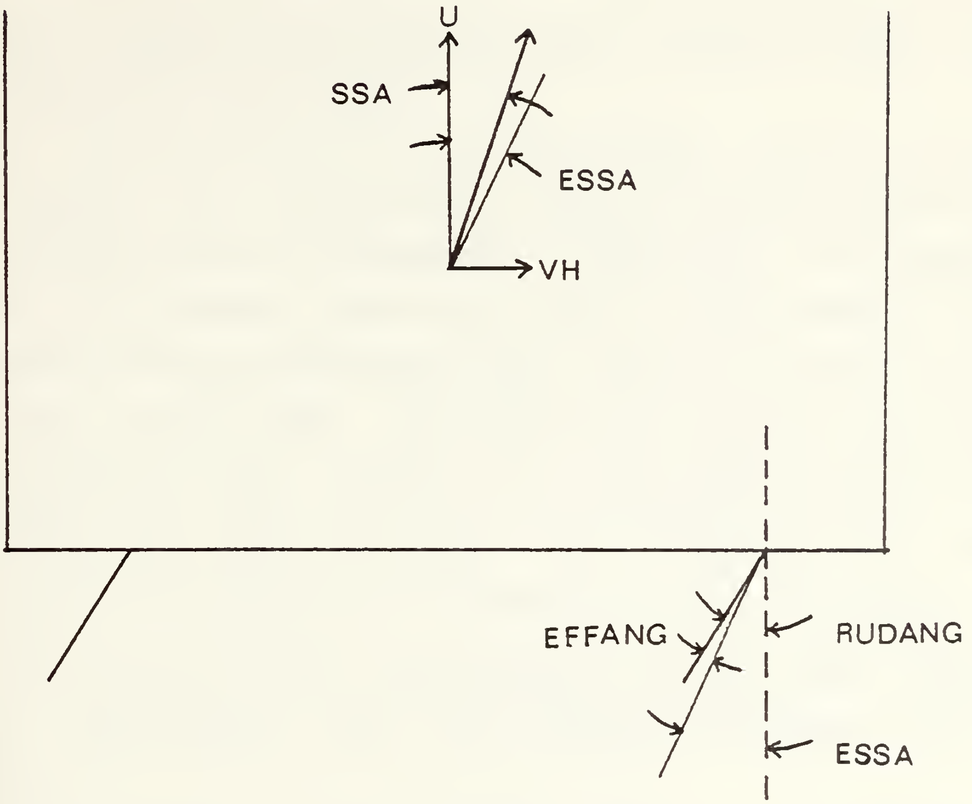
```
DSR=Z+ZS-XR*THETA
ENDFAC=1. + DSR/(DSR+RSPAN)
VH=V + XR*R - ZR*P
EFFANG=RUDANG - ENDFAC*VH/U
FY=RHO*U*U*RAREA*ENDFAC*RCLB*EFFANG
•
FK= -ZR*FY
```

The above equations compute

- draft at the rudder location
- endfactor depending on the rudder length below the craft's keel
- sideslip velocity
- effective rudder angle depending on the craft's forward and sideslip velocities
- lateral force depending on rudder area and effective rudder angle
- roll moment due to rudder .

The sign of the roll moment FK is dependent on the sign of the lateral force FY which depends on the sign of the effective rudder angle EFFANG. This in turn depends of course on the introduced rudder angle, but the magnitude of the second term of this equation (sideslip angle) is responsible for the actual sign of EFFANG. VH/U represents the tangent of the sideslip angle which - applying small angle approximation - is subtracted from the introduced rudder angle (see Figure 9). Since ENDFAC=1.73 and U was the same for both runs, a difference in VH which was larger in Leo and Boncal's version by about 50 % caused the negative sign (versus a positive sign using Forbes' version) for the effective rudder angle EFFANG and thereby FY. So the only way to introduce a change toward an inward roll behavior here (FKRUD was positive) is to first check the input value for RSPAN and second to eventually modify the craft's engines to have larger immersion into the water.

With regard to the first item, if RSPAN would increase, ENDFAC would decrease as would the magnitudes of EFFANG (negative), FY (negative) and FK (positive).



SSA = VH/U	sideslip angle
ESSA=ENDFAC*VH/U	effective sideslip angle
RUDANG	rudder angle
EFFANG	effective rudder angle

Figure 9 - EFFECTIVE RUDDER ANGLE IN A TURN MANEUVER

Considering next the fact that the engines of the XR-3 had been replaced in 1976 a recent measurement of the rudder and propeller location yielded the following data (original input values shown in parantheses) :

XPO = -1.50 (-1.275)
ZPO = -1.333 (-0.604)
XRO = -1.083 (-1.125)
RSPAN= 1.333 (1.21)
RAREA= 1.42 (0.68)

Two of the runs discussed in the preceding section have been repeated using the original roll damping term and the new propulsion and rudder input parameters.

1. Thrust is mapped with deadrise force contributions from both sidewalls with C_h=0.4 .

Comparing plots 77-78 with the corresponding ones for the former rudder and propulsion parameters (plots 63-64) the expected effect due to a decrease in FKRUD can be observed resulting in smaller peak roll angle (1.34° versus 1.45°) and a significantly decreased steady state roll angle (0.65° versus 0.99° at t=50 sec). The transient period of the roll angle response in plot 77 shows the same number of transient oscillations as plot 63 but the response did not reach steady state even after 45 sec . The steady state roll angle could be estimated to be about 0.3 to 0.4 degrees.

2. Same conditions as in the previous run but with deadrise force contribution from the outward sidewall only and C_h=0.8 .

Regarding plots 79-80 versus plots 71-72 a similar effect as mentioned before is observed. Now the roll angle response shows a more oscillatory transient period. The peak roll angle reduced from 1.46 to 1.36 degrees while the roll angle at t=50 sec changed from 1.34 to 0.97 degrees. For this run the steady state roll angle could be estimated to be about 0.8 degrees since the roll angle response again did not reach steady state for the run using the recently determined rudder and propulsion parameters. The initial small negative roll angle which appeared in the previous run (plot 77) at the moment when the rudder motion is introduced, does not show up any more. The overall roll response shown in plot 79 does not fall off as steeply (compared to plot 77) if, in a turn maneuver, deadrise force contribution from the outward sidewall only is considered.

From these runs it is obvious that the rudder and propulsion parameters of the new engines result in a more favorable XR-3 roll behavior with a significantly less steady state outward roll angle. At the time of this sensitivity study Reference 7 pointed out that there actually is no roll angle indicated by the measuring devices in a port turn at 20 knots and 12 or 15 degrees rudder angle. Keeping the device sensitivity of ±0.5 degrees in mind, it can be concluded that the steady state roll angle provided by the present XR-3 Loads and Motions Program including the before mentioned program modifications by the author, is quite well in agreement with the actual craft data. Further efforts should be undertaken to obtain a better damping effect during the transient period.

Remark :
Although the new engines extend about 0.5 ft deeper into the water than the old engines, the new input value for RSPAN is close to the former value. In Reference 1 the denominator of the second term in the equation for ENDFAC is defined to be the distance from the water surface to the bottom tip of the rudder. The equation for ENDFAC used in the present program accounts for changes in draft DSR in both the numerator and the denominator. The RSPAN-term should then be defined to be the distance from the craft's keel to the bottom tip of the rudder. The author suspects that formerly there has been chosen too large a value for RSPAN in the case of the old engines (RSPAN=1.21 ft, probably from water surface to bottom tip of the rudder). Since the bottom tip of the rudder and the center of the propeller were located at almost the same distance from the craft's keel the magnitudes of ZPO and RSPAN should be about the same which is not true for the former chosen values. From these observations the author concludes that until now a too optimistic roll behavior resulted due to a too large value for RSPAN.

V. CONCLUSIONS AND RECOMMENDATIONS

The preceding sections of this chapter reflect the results of an investigation on how the XR-3 roll behavior in turn maneuvers at 20 kn simulated with the Loads and Motions Program is affected by certain changes in parameters and forces. The results of this sensitivity study are summarized as follows :

* Added mass effect

A reformulation of the vertical added mass computation which reduced the A33s-value by a factor of 1/PI had only a little effect in changing steady state draft, pitch angle and required thrust for constant speed in straight runs. In turn maneuvers this change resulted in less damped responses for pitch and roll angle and affected the steady state values for pitch angle by +8.3 % , roll angle by -1.0 % and draft by +1.4 % . Considering the roll behavior, the effect of reducing the A33s-value by a factor of 1/PI in the vertical added mass computation was negligible.

A change in the lateral added mass coefficient C_h=0.4 to 0.8 had the effect of reducing the amplitudes of the transient oscillations and the steady state roll angle by 0.1 degree toward the experimentally measured value. Since in a turn maneuver with 15 degrees rudder angle an unstable craft behavior showed up which had not been experienced in practice, the value of C_h=0.8 is not realistic if deadrise force contributions from both sidewalls are considered. If deadrise force contribution from the outward sidewall only

is used in the simulation program the increase in lateral added mass coefficient causes an increase in the steady state roll angle by about 0.1 degree. But since now the roll angle response is quite significantly damped and resembles a step as it does in practice, the choice of the larger coefficient (0.8) seems to be appropriate for the case of the deadrise force contributed from the outward sidewall only.

* Deadrise angle effect

The deadrise angles over the length of the curved XR-3 sidewalls are not uniform. Changing the deadrise angle which is used in the deadrise force computation from the transom (78.8^{o}) to the center of gravity (58.5^{o}) resulted in more damped responses for pitch and roll motion in turn maneuvers. For all chosen rudder angles generating port turns at 20 kn the steady state roll angle changed favorably by 23 to 38 % toward the corresponding roll angle measured experimentally and documented in Ref. 6.

* Cross-flow drag coefficient

Changing the cross-flow drag coefficient (CDSW=1.28 for a long flat plate) to lower values, e.g. CDSW=1.00 , the testcraft's simulated roll behavior could be forced to match the measured steady state values. But since this coefficient has been chosen arbitrarily and cannot be declared to be appropriate for the actual XR-3 sidewalls (CDSW=1.0 means that there is no effective drag coefficient) this CDSW-value has not been considered any longer. Another suggested cross-flow drag coefficient CDSW=1.16 [Ref. 3] resulted in about 5 % reduction in steady state roll angle and a shorter transient period (about 20 %) with smaller amplitudes of oscillation than did the runs using CDSW=1.28.

* Thrust mapping

Performing thrust mapping in the simulation runs using the data provided in Ref. 6 and assuming that both engines lose equal amounts of thrust in turn maneuvers, the simulated steady state roll angles could be shown to agree better with the measured angles by about another 10 % but the roll angle response did not quite reach steady state even after 45 seconds.

* Deadrise force from outward sidewall only

The simulation runs executed with the deadrise force computed for the outward sidewall only and thrust mapping as done before, showed less agreement for both C_h=0.4 (0.8) with the corresponding measured steady state roll angles than did the runs considering deadrise forces from both sidewalls. But for C_h=0.8 the roll angle response was significantly damped and looked more like a step, as was experienced in practice.

* Vertical location of the center of gravity

The given value for the vertical location of the center of gravity (2.54 ft above the keel) might not be quite correct due to the difficulties in experimentally determining it. The significant effect of the vertical center of gravity location on the XR-3 roll behavior is obvious from Figures 1 and 8 and the discussion in Section III.F. Since it controls exceedingly the XR-3 roll behavior it is important that future investigators obtain an accurate measurement of the C.G. location before taking testcraft data.

* Subroutine PROP

A review of the propulsion subroutine revealed that the force and moment calculations as given by Leo and Boncal (Ref. 8) should be used instead of the version stated by Forbes (Ref. 9). This change results in a 7 % larger outward steady state roll angle but it provides a reasonable roll moment due to the propulsion system.

* Roll damping due to vertical wave generation

The roll damping calculation included in subroutine SIDEWALL has only a negligible effect on the craft's net roll behavior over the range of the damping factor 1.0<PROMO2<50.0 . Since there also is a discrepancy in the dimension of the roll damping term the source of this part of the program should be investigated.

* Suggested areas for further investigation

During the studies undertaken with the XR-3 Loads and Motion Program the author found the following points either in the input data from the testcraft or in the program that require further investigation :

- Rudder/thrust angle

As learned from Ref. 7 the rudder/thrust motion is directly introduced to the port engine while the starboard engine follows this via a metal bar connecting both engines. The starboard rudder and thrust vector may be off by 2 or 3 degrees to either side, depending on the direction of the rudder/thrust action. Thereby the roll behavior will certainly be effected. Since rudder/thrust mapping is available in the Loads and Motion Program, it is important that accurate data be collected for each engine during a test run.

- XR-3 weight

During each test run there is a possibility that the weight is not exact since, as learned from Ref. 7, the testcraft takes on water in the seals and thereby its weight increases causing larger draft which also effects the roll behavior. This additional weight can be substantial and attempts should be made to measure or estimate the additional weight to be used in the Loads and Motion Program.

- Cross-flow drag coefficient

Further efforts should be undertaken to establish the proper value of the cross-flow drag coefficient since CDSW=1.28 might not be quite appropriate for the actual shape of the XR-3 sidewalls.

- Sideslip velocity

Those parts of the Loads and Motions Program where terms contributing to the lateral velocity V are computed should be reviewed since a large value of V may result in a change in the effective rudder angle from positive to negative.

In this sensitivity study it has been shown that the most significant effect on the simulated XR-3 roll behavior are contributed by

* deadrise angle

* vertical location of the center of gravity

* rudder and propeller location .

Less significant effects are contributed by

* thrust mapping

* cross-flow drag coefficient .

For further studies concerned with the XR-3 Loads and Motions Program for improved roll behavior representation it is recommended to use

- the reformulated equation for the vertical added mass A33

- deadrise angle at the center of gravity location

- deadrise force contribution from the outward sidewall only

- subroutine PROP as given by Leo and Boncal and in Appendix C of this thesis

- thrust and rudder mapping.

APPENDIX A

PLOTS

In the table given below are listed all plots with the respective parameters used in the corresponding simulation run. The table contains the following abbreviations :

COEF	coefficient	CG	center of gravity
CDSW	sidewall drag	C_h	lateral added mass coef.
ch4	chapter IV		
DRANG	deadrise angle	DF16	PROMO2=16.0
PA	pitch angle	PR	pitch rate
RA	roll angle	RR	roll rate
REFTAB	refer to table	RUDANG	rudder angle
TR	Transom		

L-B Leo and Boncal's version of subroutine 'PROP' used

P*|P| or P*PI P replaced by ... in SDWL2200 (Section III.G)

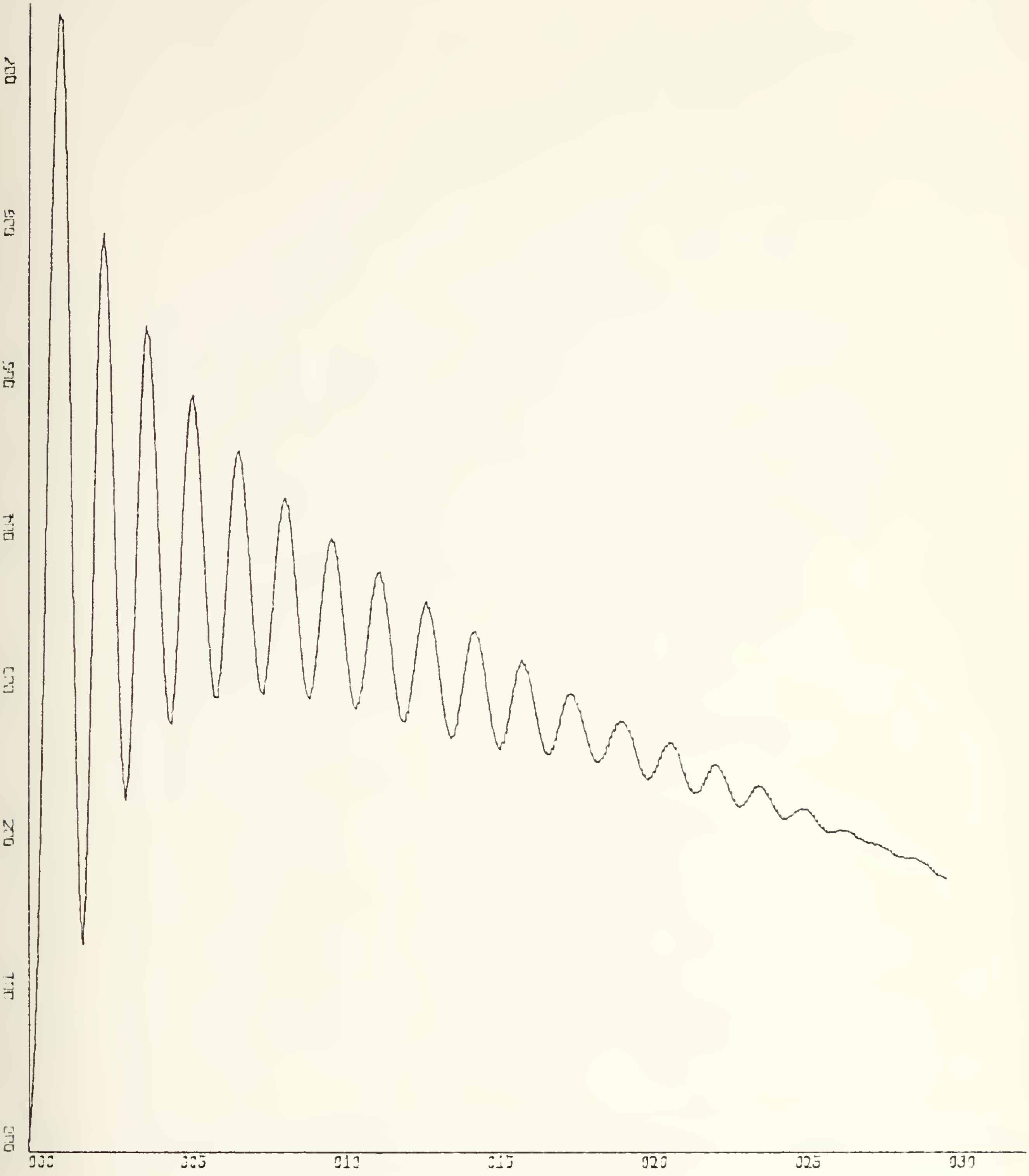
ZS-0.1 vertical location of CG is 2.54 - 0.1 (ft)

PLOT NO	REF TAB	RESP	RUD ANG	DR ANG	COEF C_h	COEF CDSW	THRUST MAP	SDWL-FORCES	REMARK
1	1	RA	35	TR	0.4	1.28	no	both	no PBAR
2	1	PA	35	TR	0.4	1.28	no	both	
3	1	RA	35	TR	0.4	1.28	no	both	with PBAR
4	1	PA	35	TR	0.4	1.28	no	both	
5	4	RA	15	TR	0.4	1.28	no	both	old A33s
6	4	RR	15	TR	0.4	1.28	no	both	
7	4	PA	15	TR	0.4	1.28	no	both	
8	4	PR	15	TR	0.4	1.28	no	both	

PLCT NO	REF TAB	RESP	RUD ANG	DR ANG	COEF C_h	COEF CDSW	THRUST MAP	SDWL-FORCES	REMARK
9	4,6	RA	15	TR	0.4	1.28	no	both	
10	4,6	RR	15	TR	0.4	1.28	no	both	
11	4,6	PA	15	TR	0.4	1.28	no	both	
12	4,6	PR	15	TR	0.4	1.28	no	both	
13	6	RA	15	CG	0.4	1.28	no	both	
14	6	RR	15	CG	0.4	1.28	no	both	
15	6	PA	15	CG	0.4	1.28	no	both	
16	6	PR	15	CG	0.4	1.28	no	both	
17	6	RA	15	CG	0.8	1.28	no	both	
18	6	RR	15	CG	0.8	1.28	no	both	
19	6	RA	12	TR	0.4	1.28	no	both	
20	6	RR	12	TR	0.4	1.28	no	both	
21	6	RA	12	CG	0.4	1.28	no	both	
22	6	RR	12	CG	0.4	1.28	no	both	
23	6	RA	12	CG	0.8	1.28	no	both	
24	6	RR	12	CG	0.8	1.28	no	both	
25	ch4	RA	15	CG	0.4	1.28	no	both	L-B
26	ch4	RR	15	CG	0.4	1.28	no	both	L-B
27	ch4	PA	15	CG	0.4	1.28	no	both	L-B
28	ch4	PR	15	CG	0.4	1.28	no	both	L-B
29	8	RA	15	CG	0.4	1.28	no	both	
30	8	RR	15	CG	0.4	1.28	no	both	
31	8	RA	15	CG	0.4	1.16	no	both	
32	8	RR	15	CG	0.4	1.16	no	both	
33	10	RA	12	CG	0.4	1.28	yes	both	
34	10	RR	12	CG	0.4	1.28	yes	both	
35	10	RA	12	CG	0.8	1.28	yes	both	
36	10	RR	12	CG	0.8	1.28	yes	both	
37	10	RA	12	CG	0.4	1.16	yes	both	
38	10	RR	12	CG	0.4	1.16	yes	both	
39	10	RA	12	CG	0.8	1.16	yes	both	
40	10	RR	12	CG	0.8	1.16	yes	both	

PLOT NO	REF TAB	RESP	RUD ANG	DR ANG	COEF C_h	COEF CDSW	THRUST MAP	SDWL-FORCES	REMARK
41	11	RA	12	CG	0.4	1.28	yes	one	
42	11	RR	12	CG	0.4	1.28	yes	one	
43	11	RA	12	CG	0.8	1.28	yes	one	
44	11	RR	12	CG	0.8	1.28	yes	one	
45	11	RA	12	CG	0.4	1.16	yes	one	
46	11	RR	12	CG	0.4	1.16	yes	one	
47	11	RA	12	CG	0.8	1.16	yes	one	
48	11	RR	12	CG	0.8	1.16	yes	one	
49	12	RA	15	CG	0.4	1.28	no	both	ZS-0.1
50	12	RR	15	CG	0.4	1.28	no	both	ZS-0.1
51	12	RA	15	CG	0.4	1.28	no	both	ZS-0.2
52	12	RR	15	CG	0.4	1.28	no	both	ZS-0.2
53	12	RA	15	CG	0.4	1.28	no	both	ZS-0.3
54	12	RR	15	CG	0.4	1.28	no	both	ZS-0.3
55	13	RA	12	CG	0.4	1.28	yes	both	ZS-0.1
56	13	RR	12	CG	0.4	1.28	yes	both	ZS-0.1
57	13	RA	12	CG	0.4	1.28	yes	both	ZS-0.2
58	13	RR	12	CG	0.4	1.28	yes	both	ZS-0.2
59	13	RA	12	CG	0.4	1.28	yes	both	ZS-0.3
60	13	RR	12	CG	0.4	1.28	yes	both	ZS-0.3
61	ch4	RA	12	CG	0.4	1.28	no	both	DF16
62	ch4	RR	12	CG	0.4	1.28	no	both	DF16
63	ch4	RA	12	CG	0.4	1.28	yes	both	DF16
64	ch4	RR	12	CG	0.4	1.28	yes	both	DF16
65	ch4	RA	12	CG	0.4	1.28	yes	both	DF16
66	ch4	RR	12	CG	0.4	1.28	yes	both	P*|P|
67	ch4	RA	12	CG	0.8	1.28	yes	one	DF16
68	ch4	RR	12	CG	0.8	1.28	yes	one	DF16
69	ch4	RA	12	CG	0.8	1.28	yes	one	DF16
70	ch4	RR	12	CG	0.8	1.28	yes	one	P*|P|
71	ch4	RA	12	CG	0.8	1.28	yes	one	DF16
72	ch4	RR	12	CG	0.8	1.28	yes	one	P*PI

PLOT NO	REF TAB	RESP	RUD ANG	DR ANG	COEF C_h	COEF CDSW	THRUST MAP	SDWL-FORCES	REMARK
73	ch4	RA	12	CG	0.4	1.28	no	both	DF16
74	ch4	RR	12	CG	0.4	1.28	no	both	L-B
75	ch4	RA	12	CG	0.4	1.28	yes	both	DF16
76	ch4	RR	12	CG	0.4	1.28	yes	both	L-B
77	ch4	RA	12	CG	0.4	1.28	yes	both	DF16
78	ch4	RR	12	CG	0.4	1.28	yes	both	P*PI
79	ch4	RA	12	CG	0.8	1.28	yes	one	new
80	ch4	RR	12	CG	0.8	1.28	yes	one	Rud



PLØT IS RØLL ANGLE VERSUS TIME

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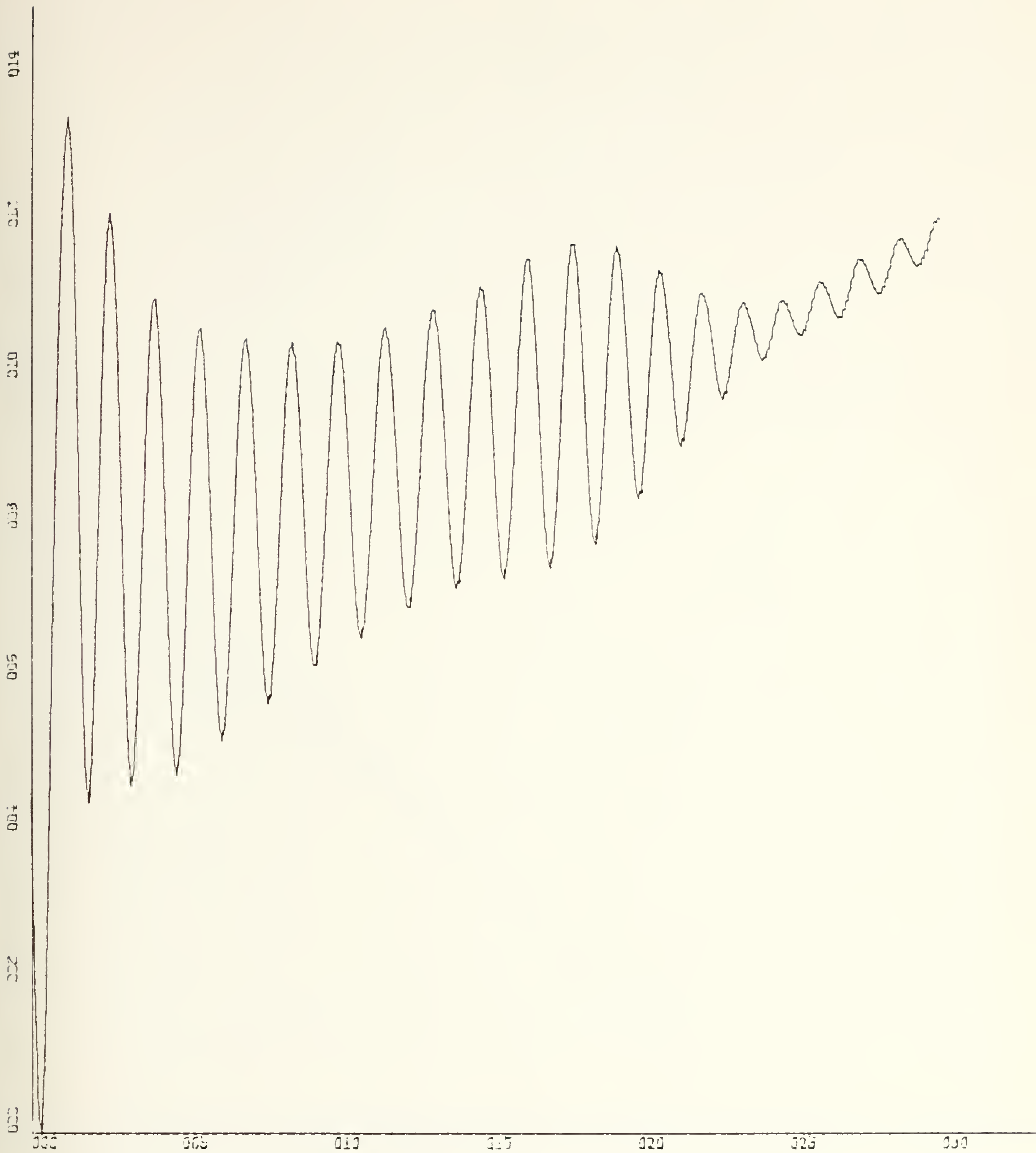
Y-SCALE=1.00E+00 UNITS INCH.

PLOT 1

for applied parameters see first page of this appendix



PLOT IS PITCH ANGLE VERSUS TIME

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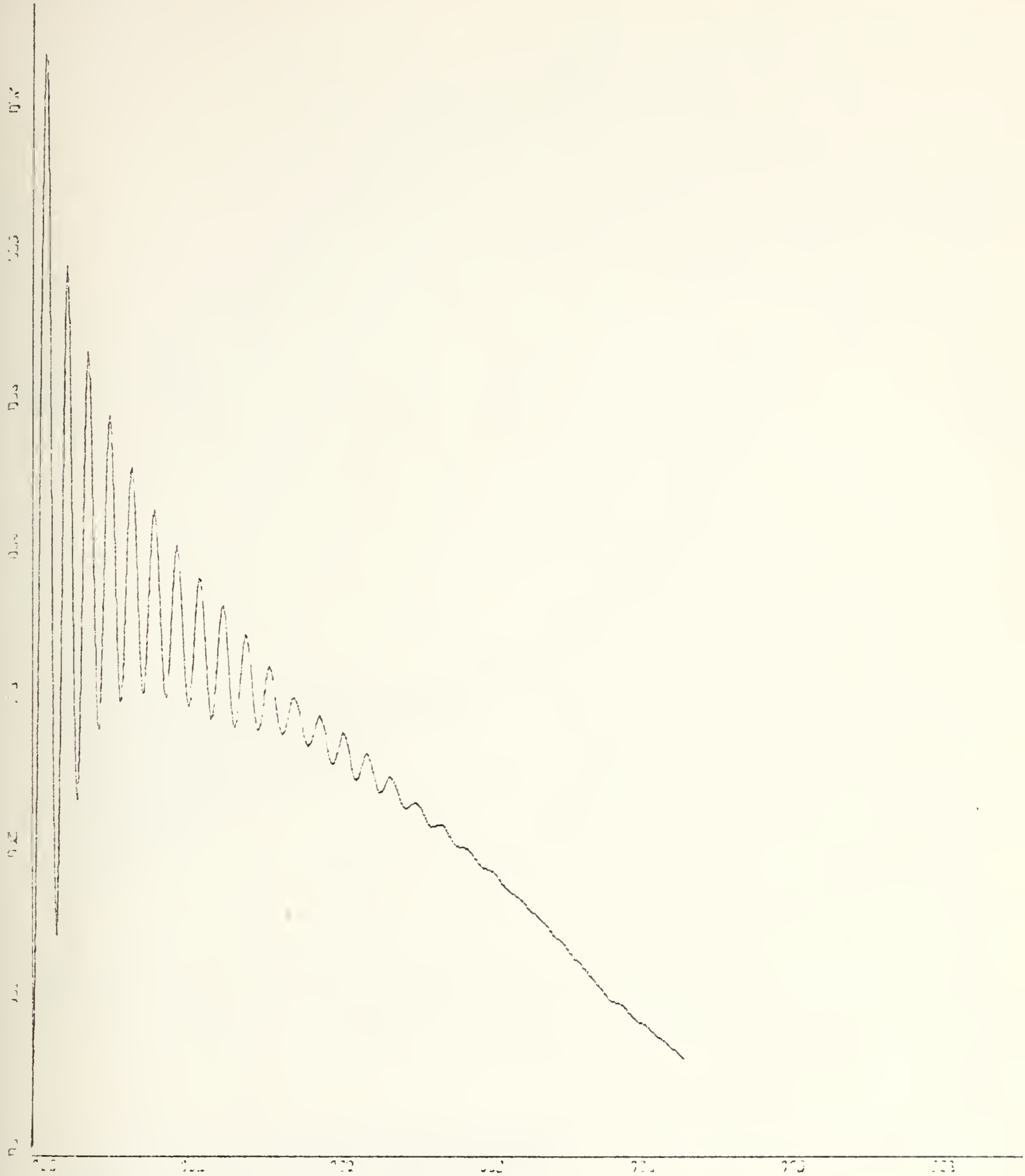
~~Y-SCALE=2.00E-01 UNITS INCH.~~

PLOT 2

for applied parameters see first page of this appendix



PLOT IS ROLL ANGLE VERSUS TIME

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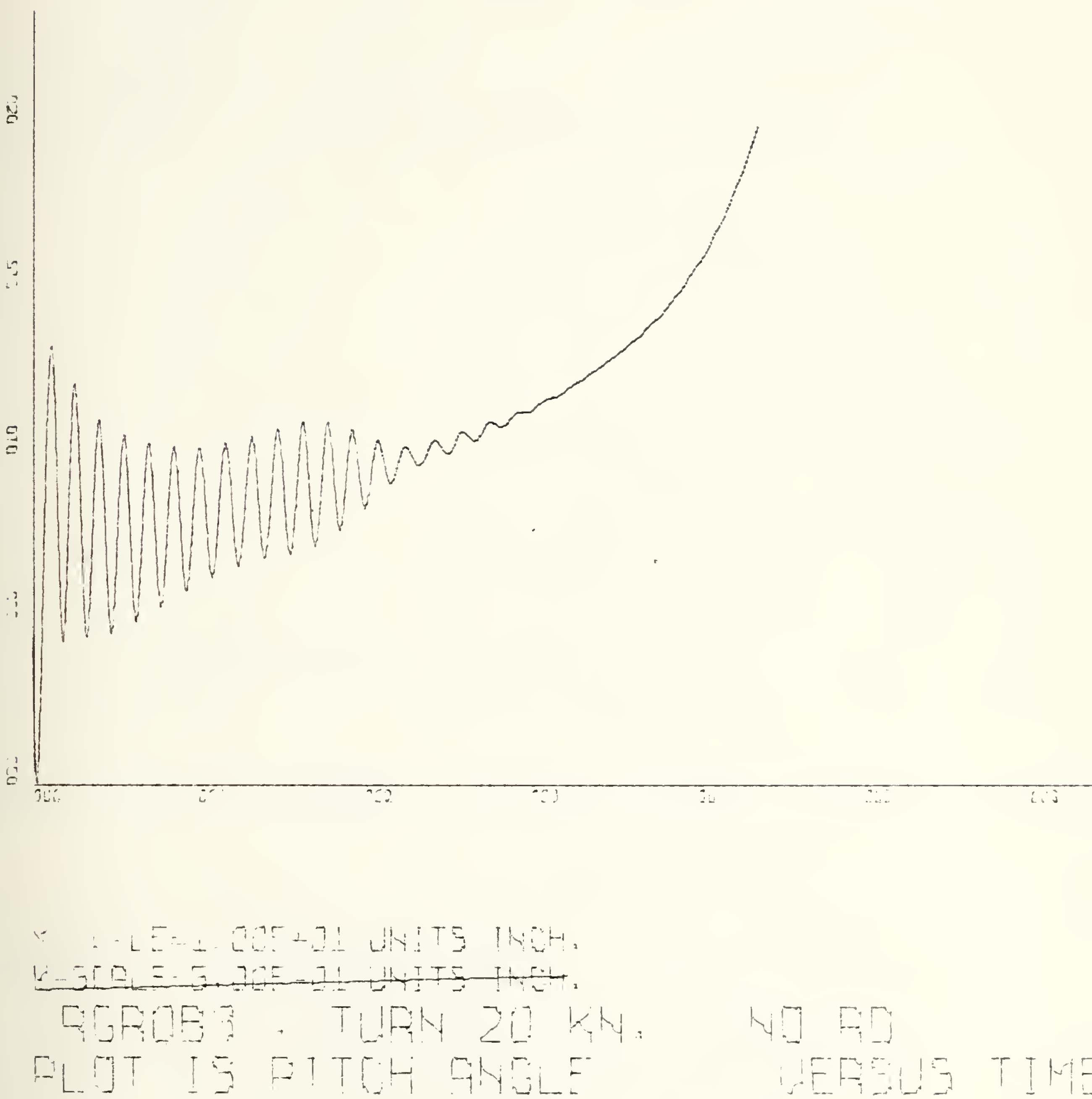
Y-SCALE 1.00E+00 UNITS INCH.

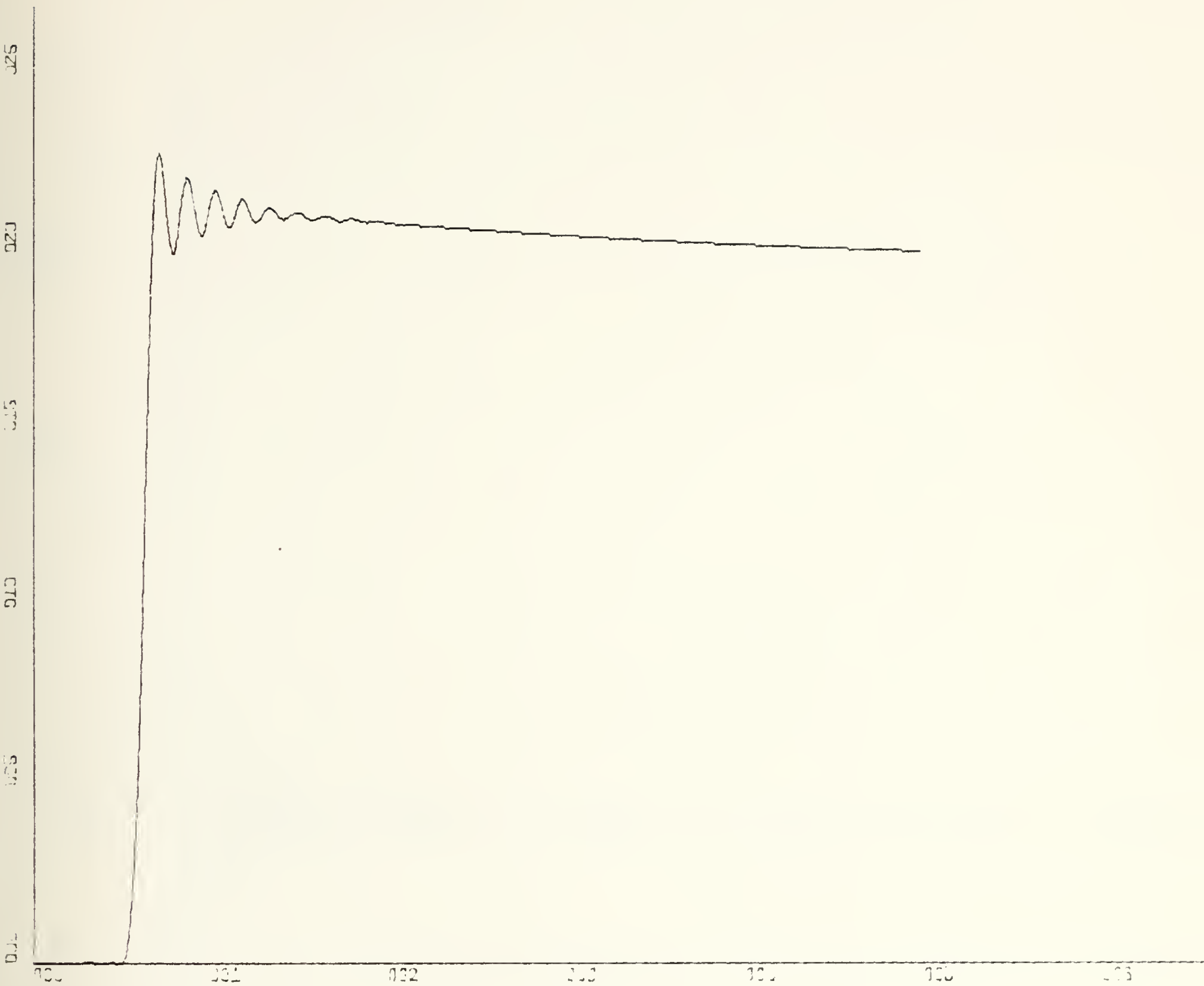
PLOT 3

for applied parameters see first page of this appendix



PLOT 4

for applied parameters see first page of this appendix



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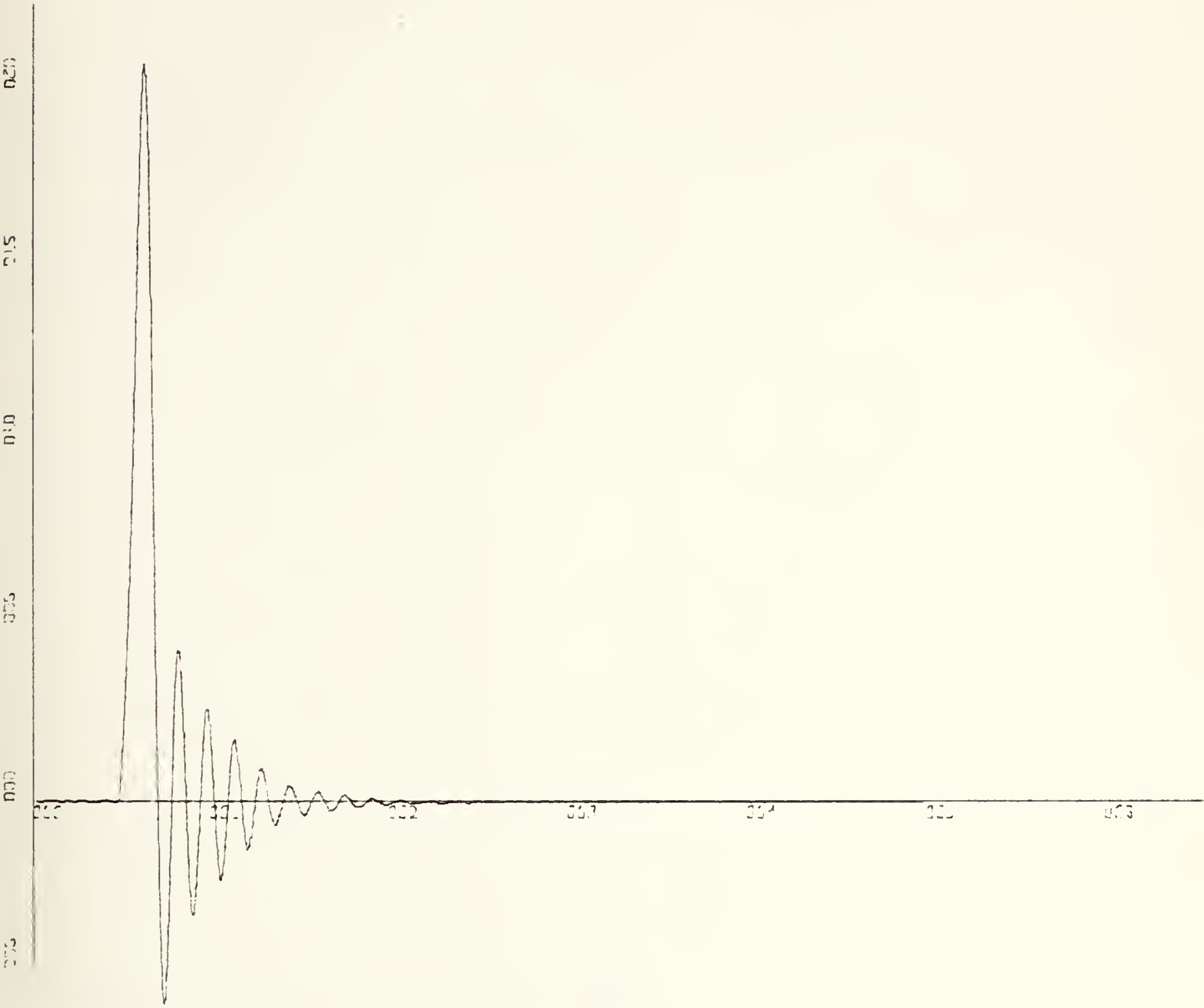
Y-SCALE=5.00E-01 UNITS INCH.
RGROD2 , TURN 20 KN , RUDM=15
PLØT IS ROLL ANGLE VERSUS TIME

PLOT 5

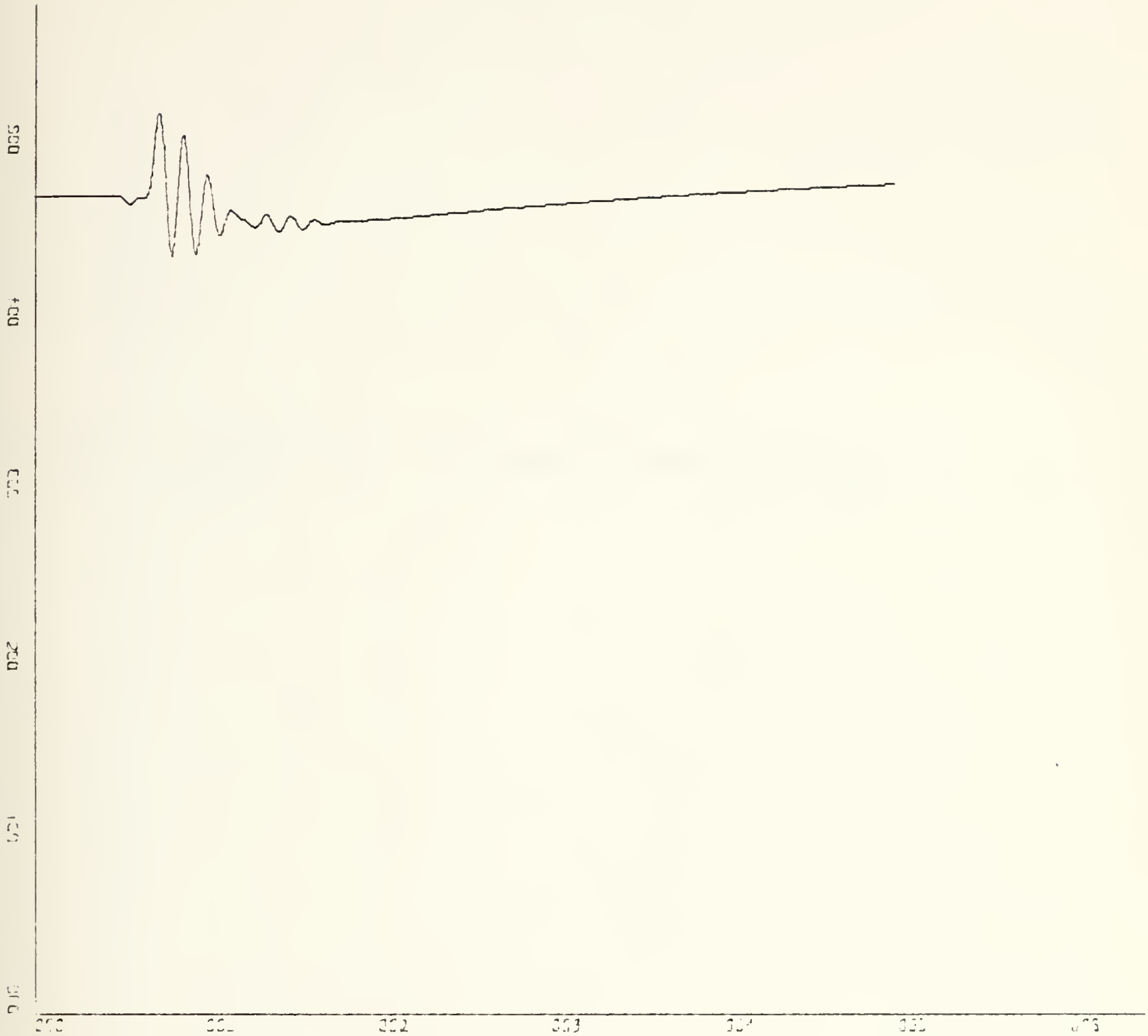
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROD2 , TURN 20 KN , RUDM=15
PLOT IS ROLL RATE VERSUS TIME

PLOT 6

for applied parameters see first page of this appendix



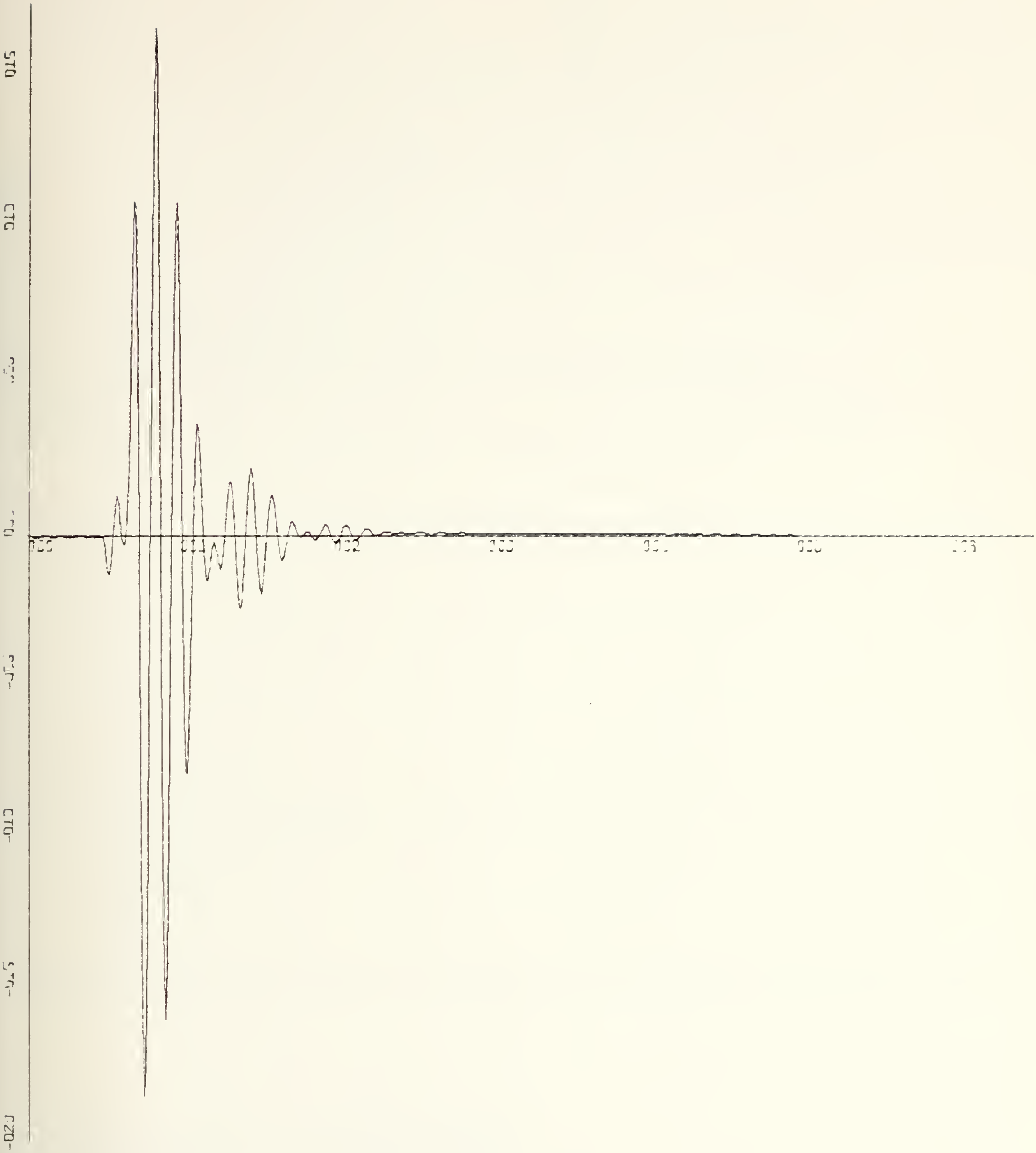
X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 1.00E-01 UNITS INCH.

ACROD2 . TURN 20 KN . RUDM=15

PLOT IS PITCH ANGLE VERSUS TIME

PLOT 7

for applied parameters see first page of this appendix



PLOT IS PITCH RATE VERSUS TIME

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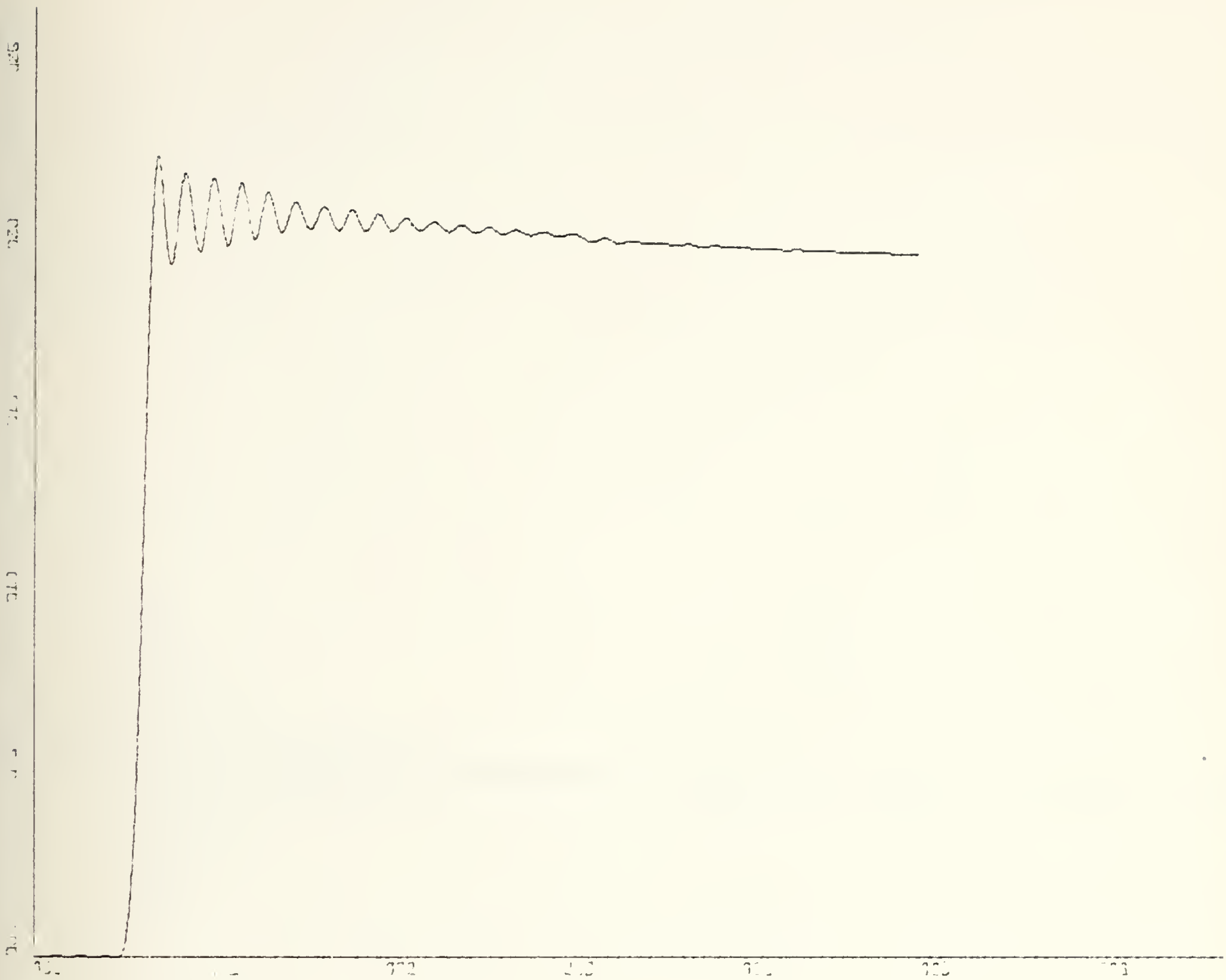
Y-SCALE=5.00E-02 UNITS INCH.

PLOT 8
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH

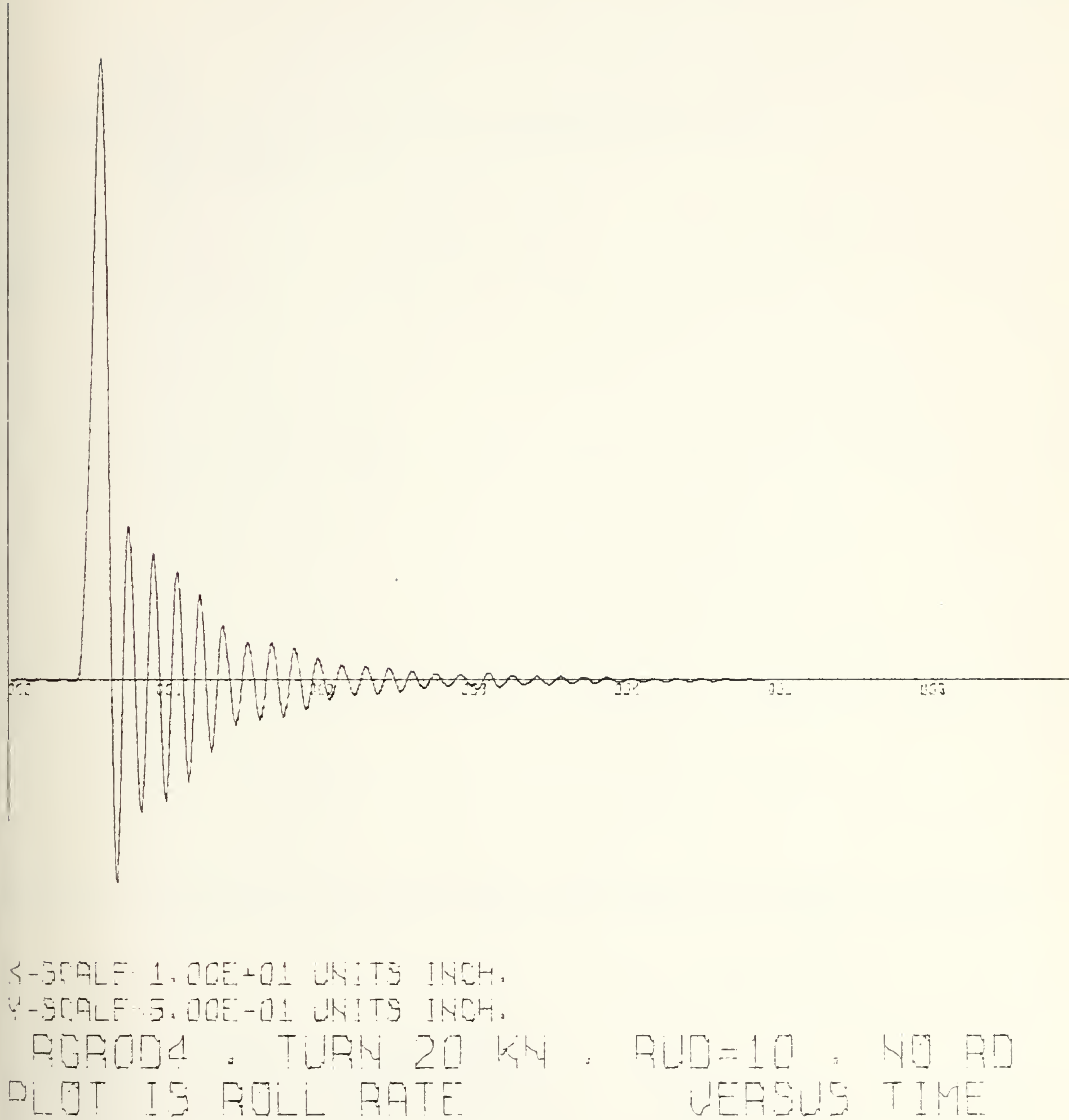
Y-SCALE=5.00E-01 UNITS INCH.

AGR004 , TURN 20 KN , RUD=10 , NO RD

PLOT IS ROLL ANGLE VERSUS TIME

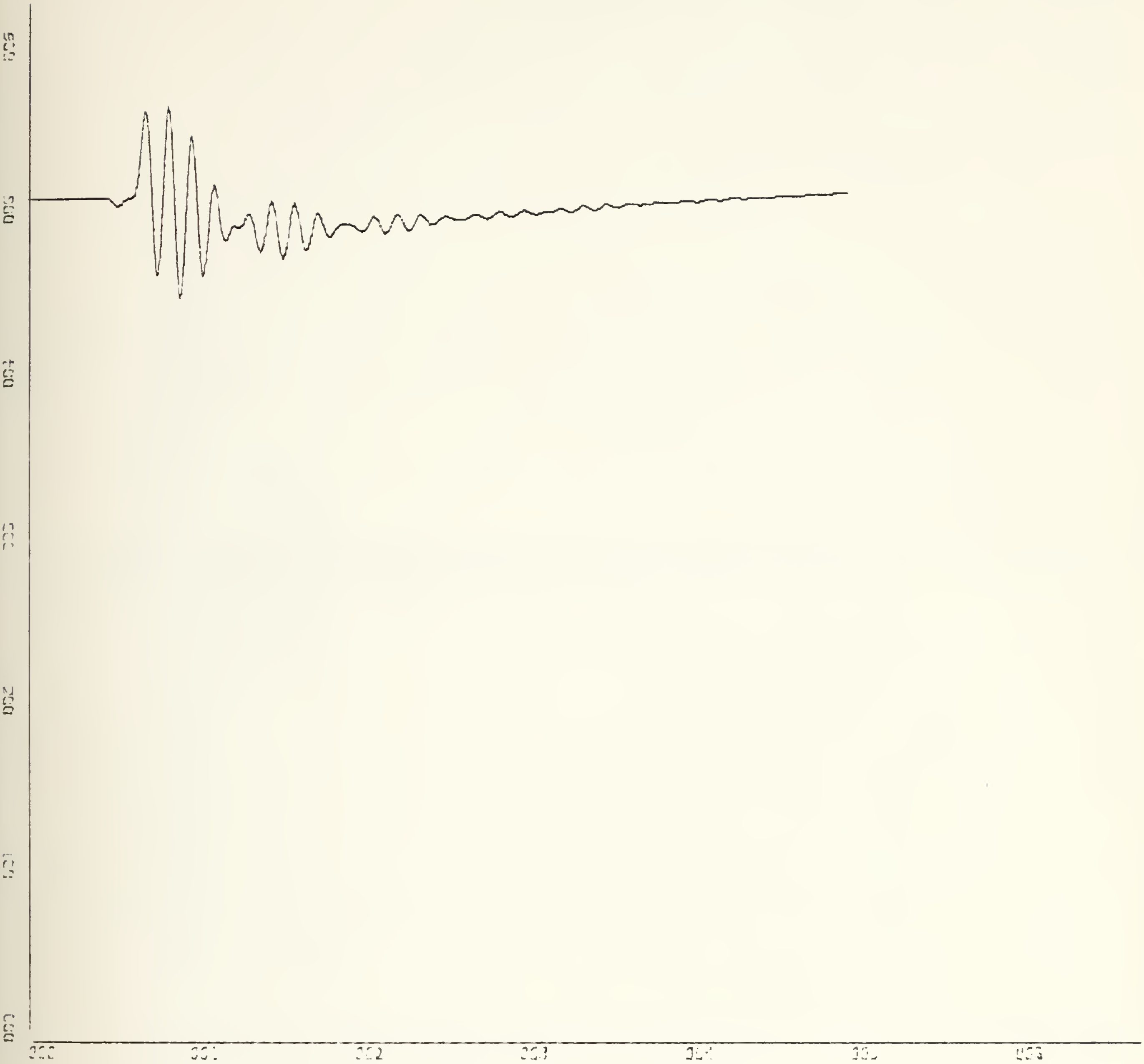
PLOT 9

for applied parameters see first page of this appendix



PLOT 10

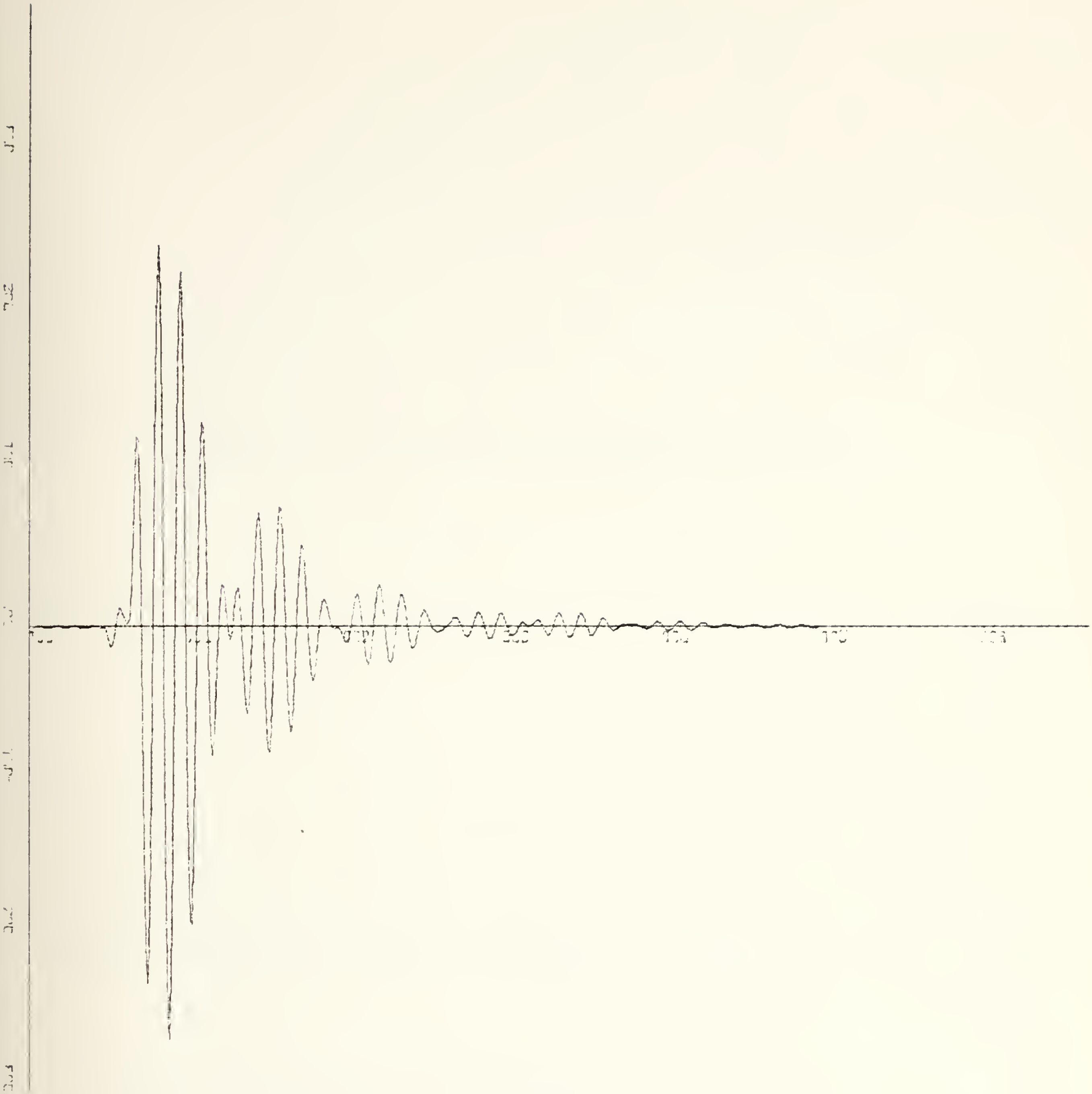
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=1.00E-01 UNITS INCH.
RGROO4 . TURN 20 KN . RUD=10 . NO RD
PLOT IS PITCH ANGLE VERSUS TIME

PLOT 11

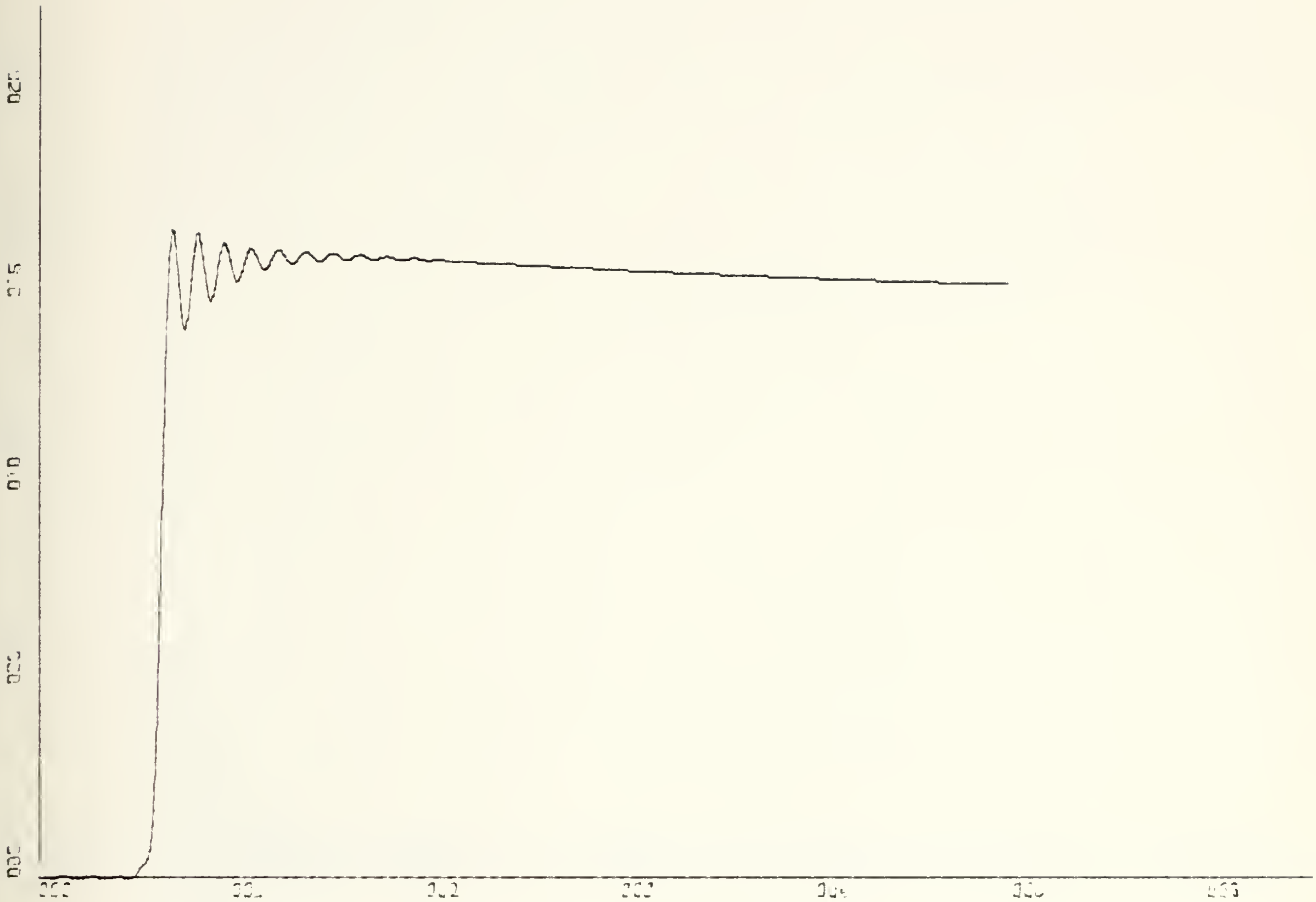
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 1.00E-01 UNITS INCH.
RGR004 , TURN 20 KN , RUD=10 , NO RD
PLOT IS PITCH RATE VERSUS TIME

PLOT 12

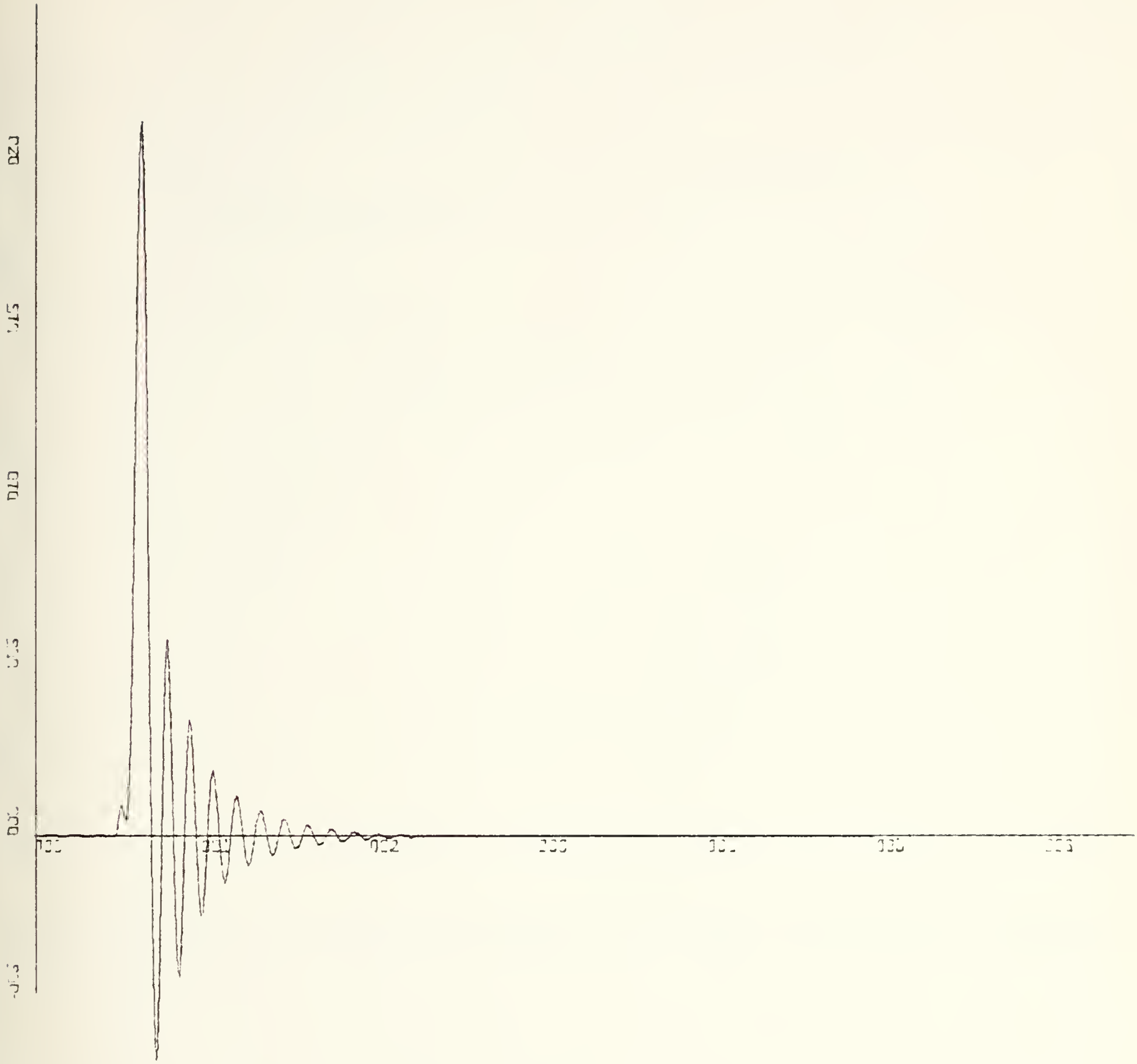
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
RGRODS , TURN 20 KN , RUDM=15
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 13

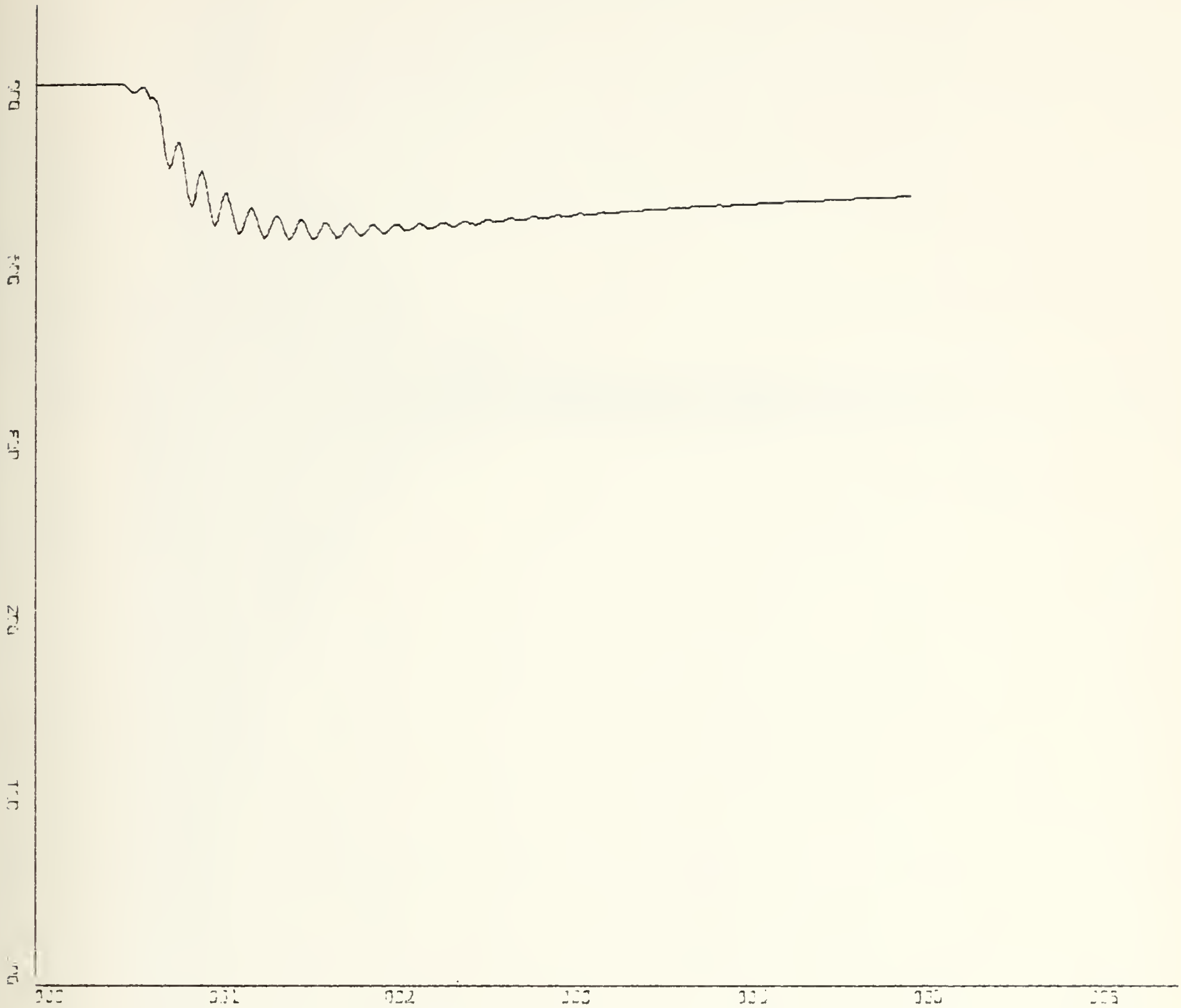
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROD5 , TURN 20 KN , RUDM=15
PLØT IS RØLL RATE VERSUS TIME

PLOT 14

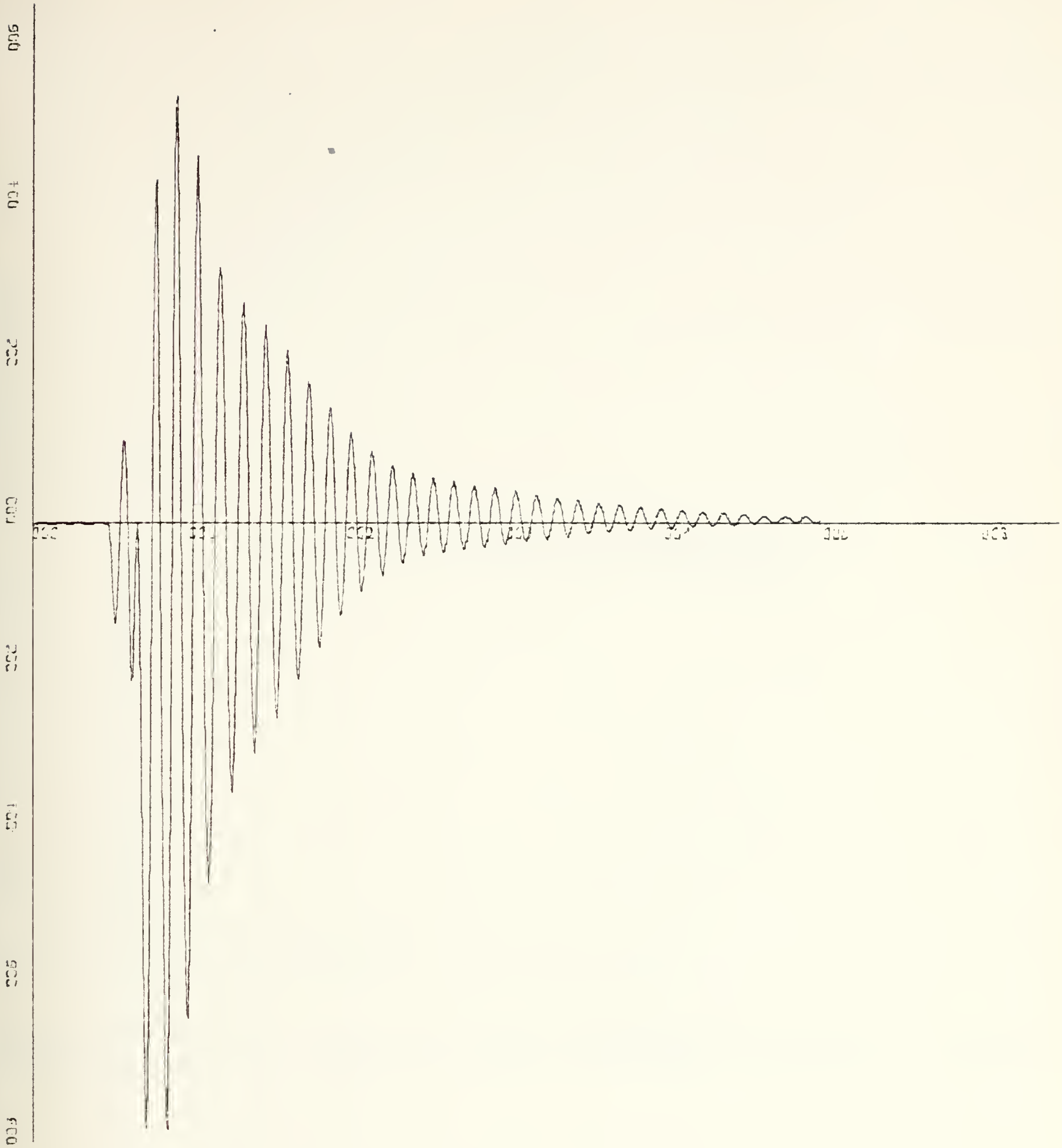
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=1.00E-01 UNITS INCH.
RGROD5 , TURN 20 KN , RUDM=15
PLOT IS PITCH ANGLE VERSUS TIME

PLOT 15

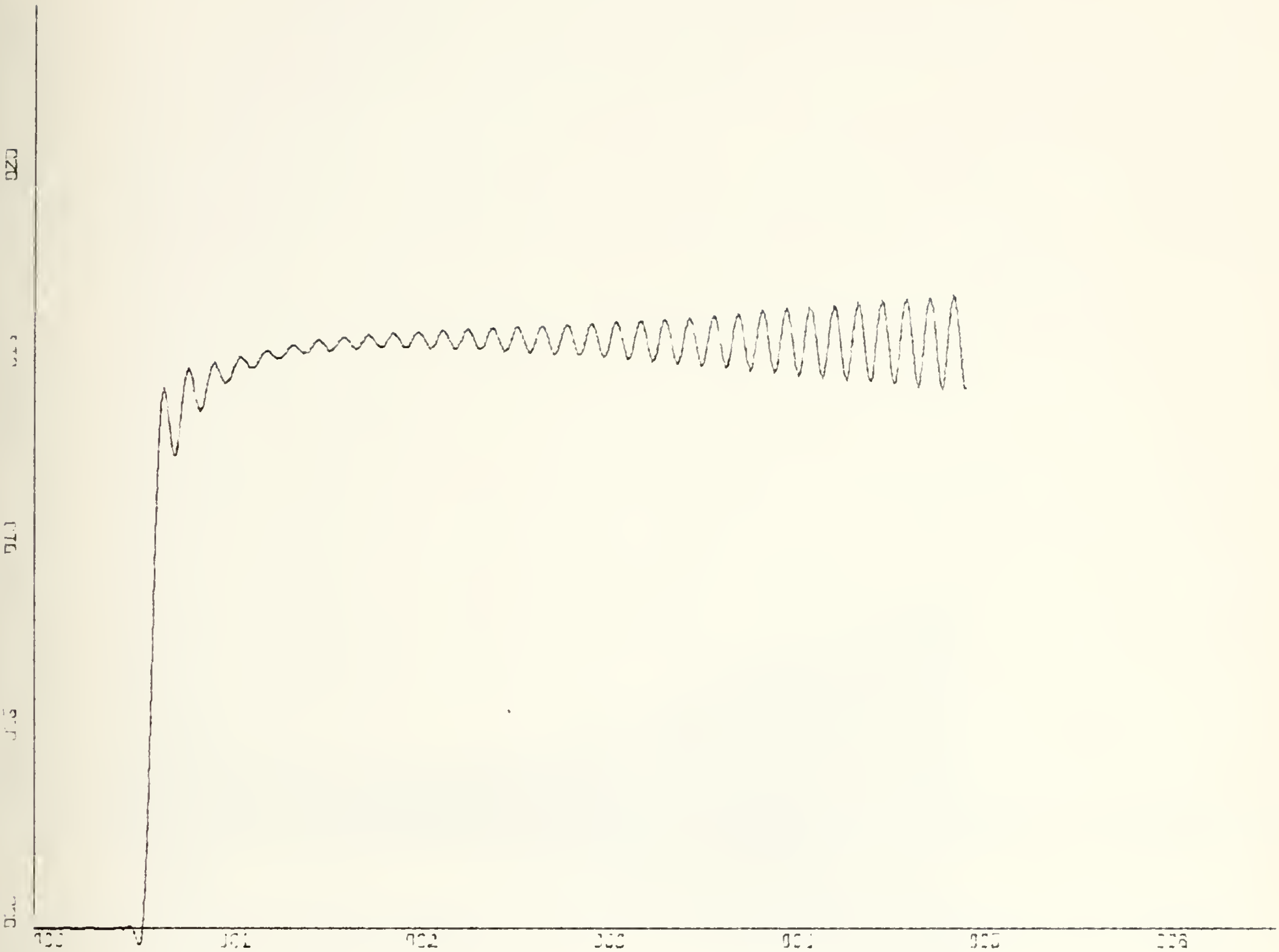
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-02 UNITS INCH.
RGRODS , TURN 20 KN , RUDM=15
PLOT IS PITCH RATE VERSUS TIME

PLOT 16

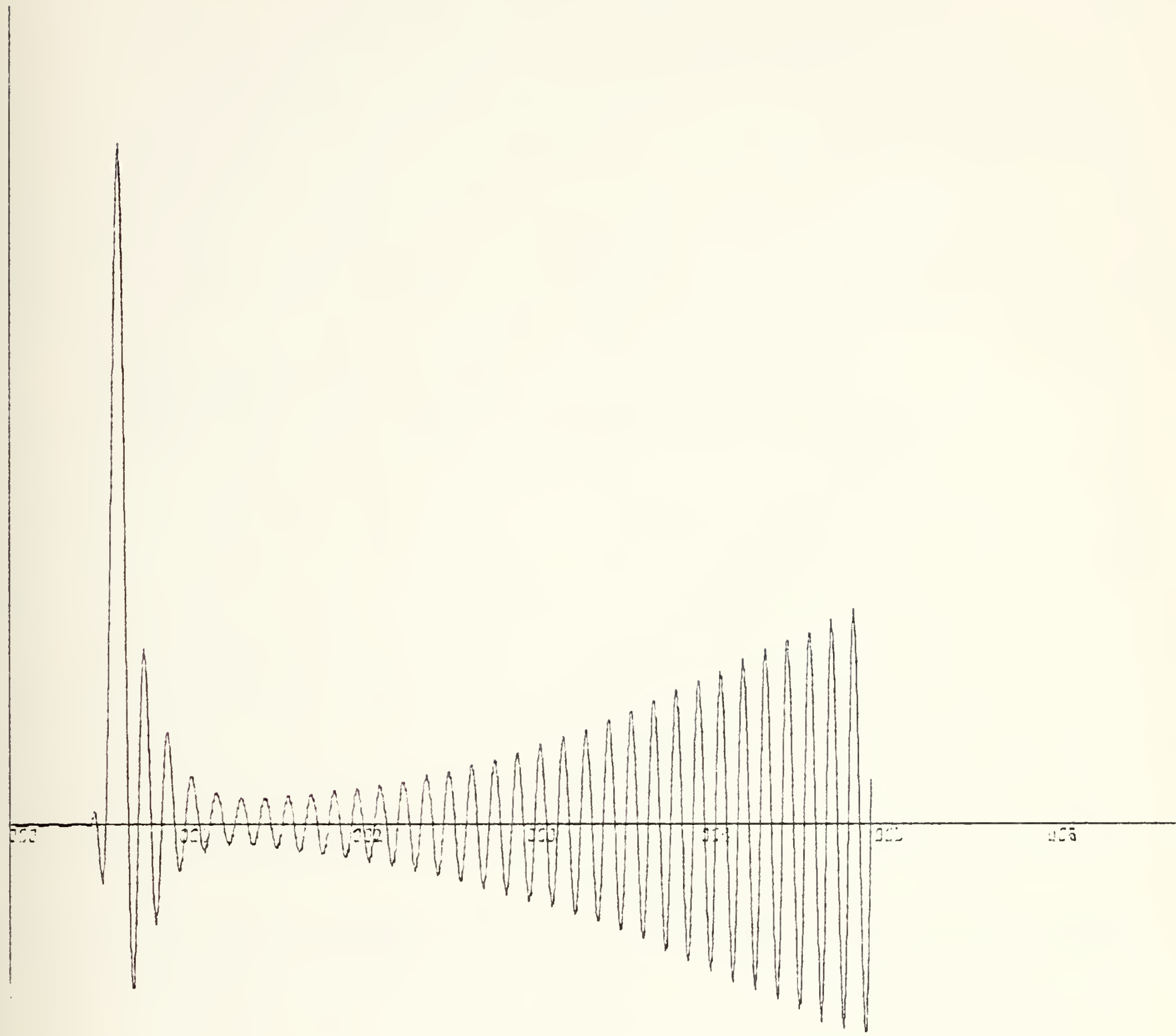
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
AGADES , TURN 20 KN , RUD=10 , NØ AD
PLØT IS ROLL ANGLE VERSUS TIME

PLOT 17

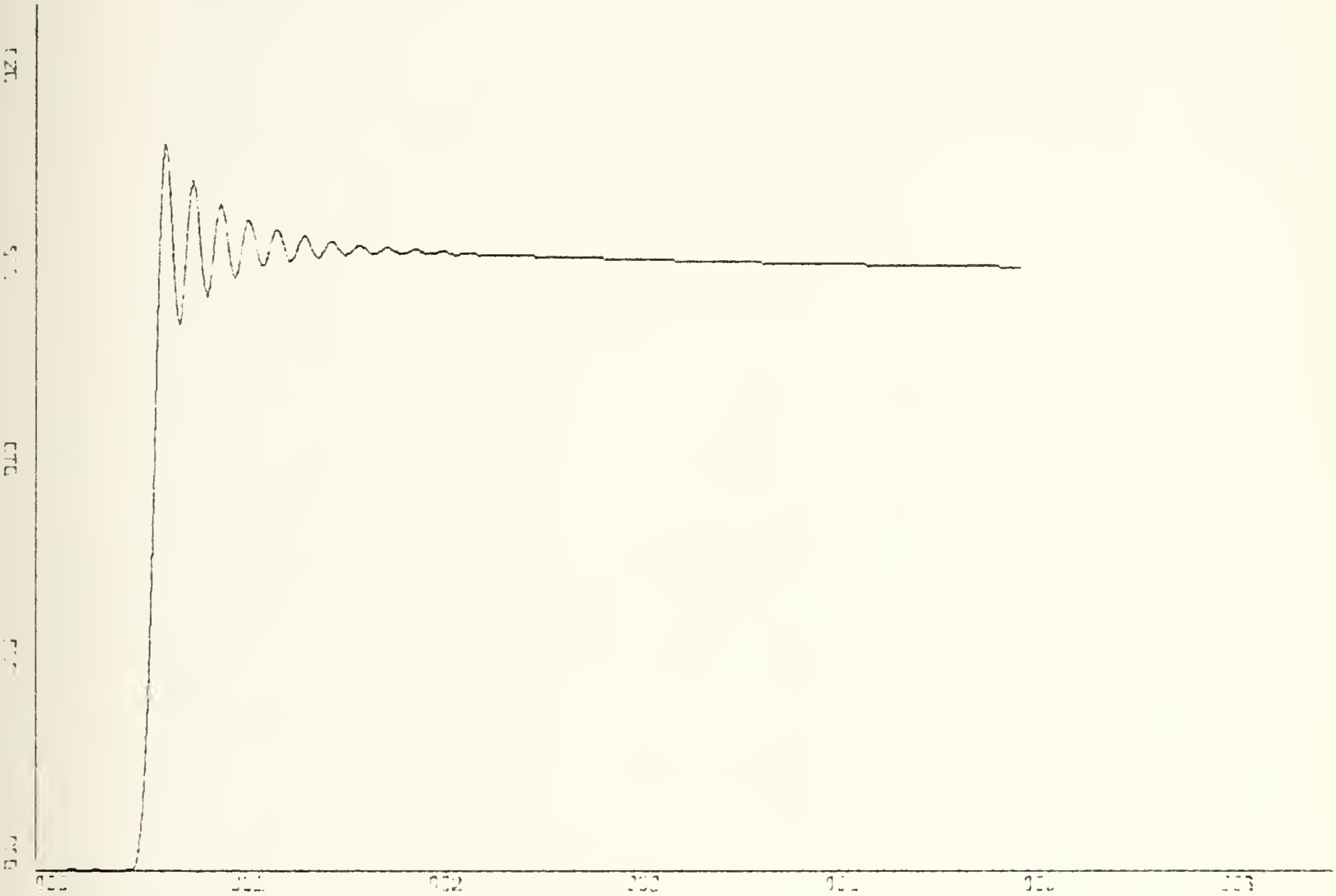
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
AGROES , TURN 20 KN , RUD=10 , NO RD
PLOT IS ROLL RATE VERSUS TIME

PLOT 18

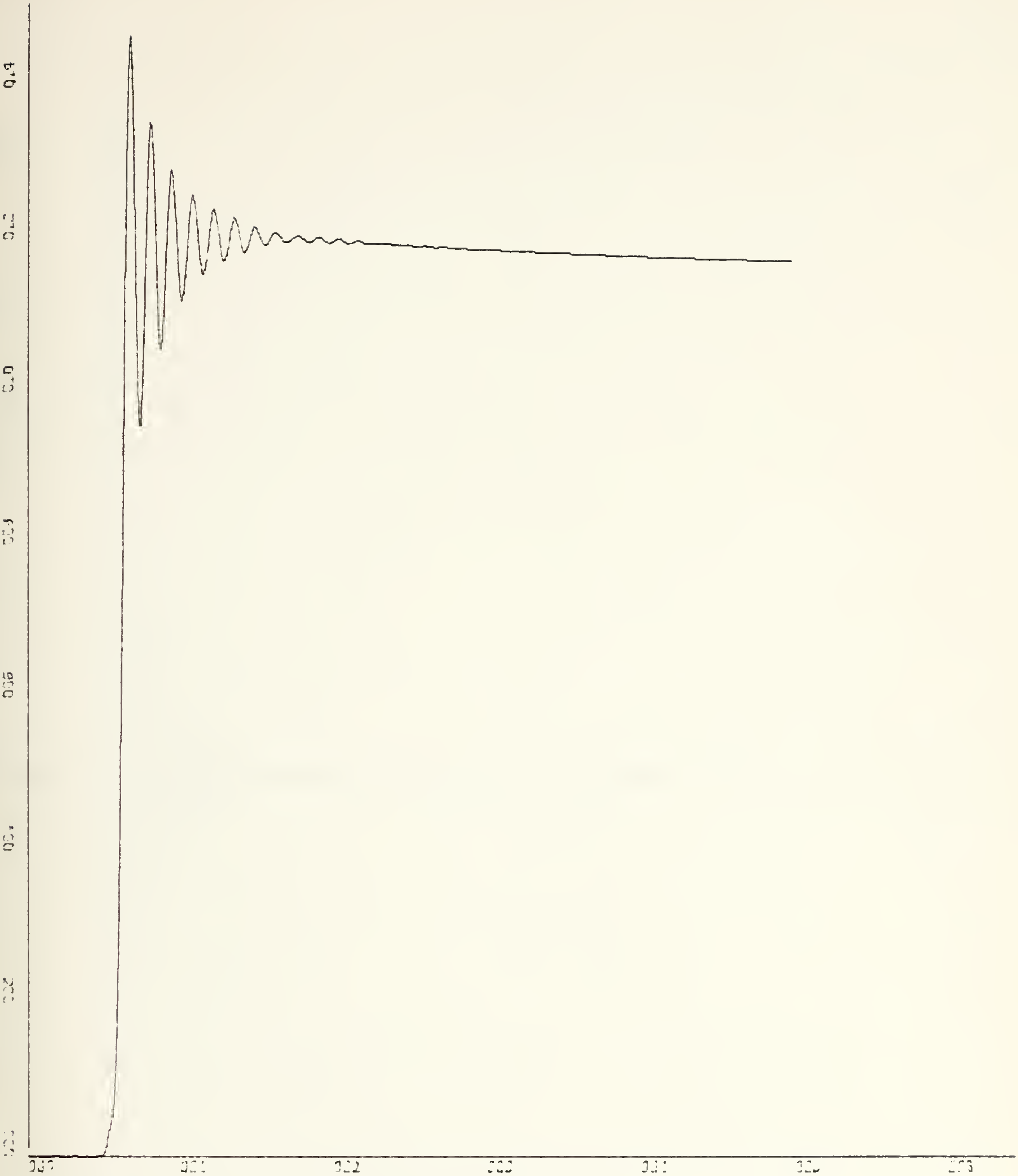
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT61 , TURN 20 KN.
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 19

for applied parameters see first page of this appendix

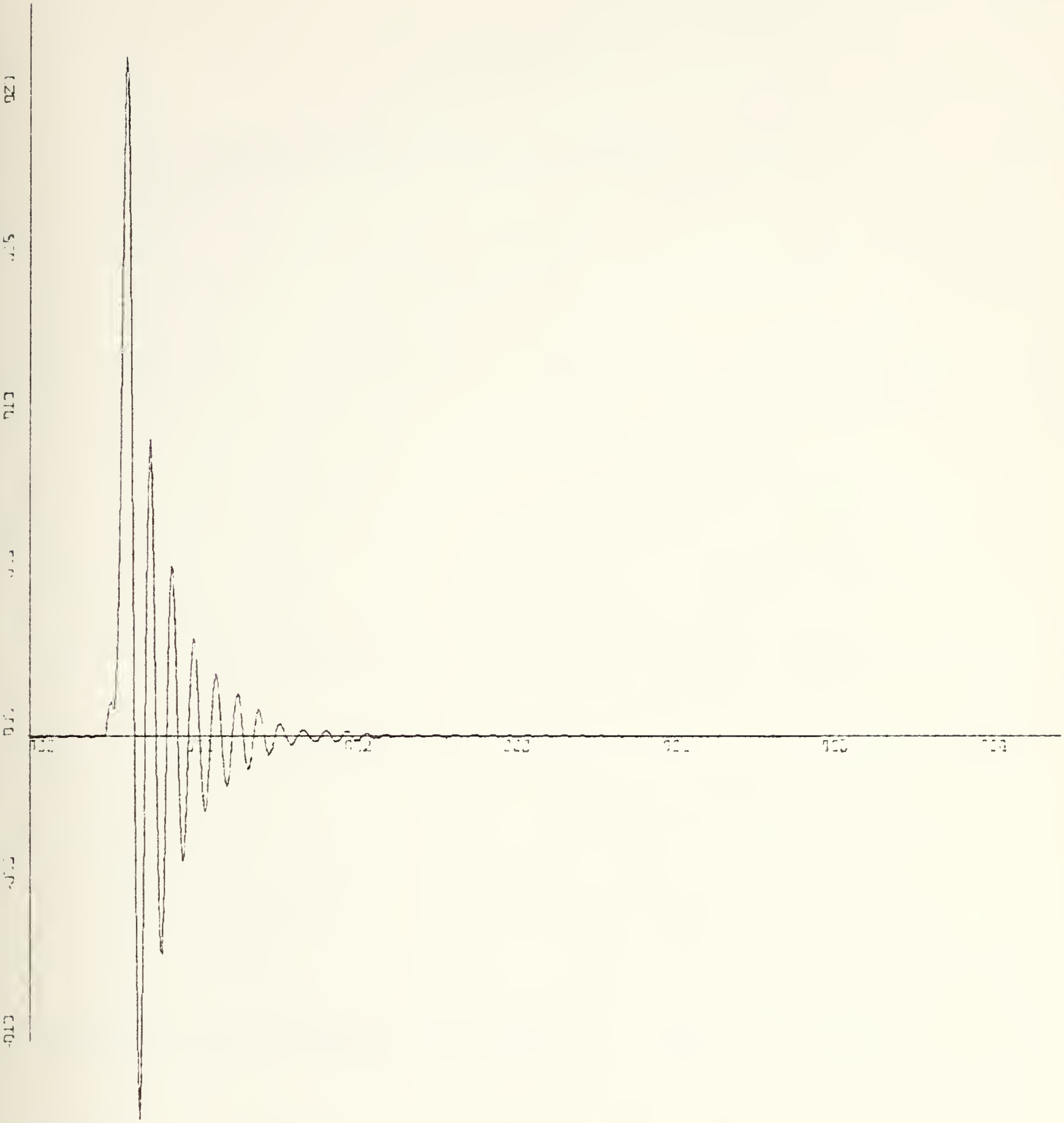


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 21

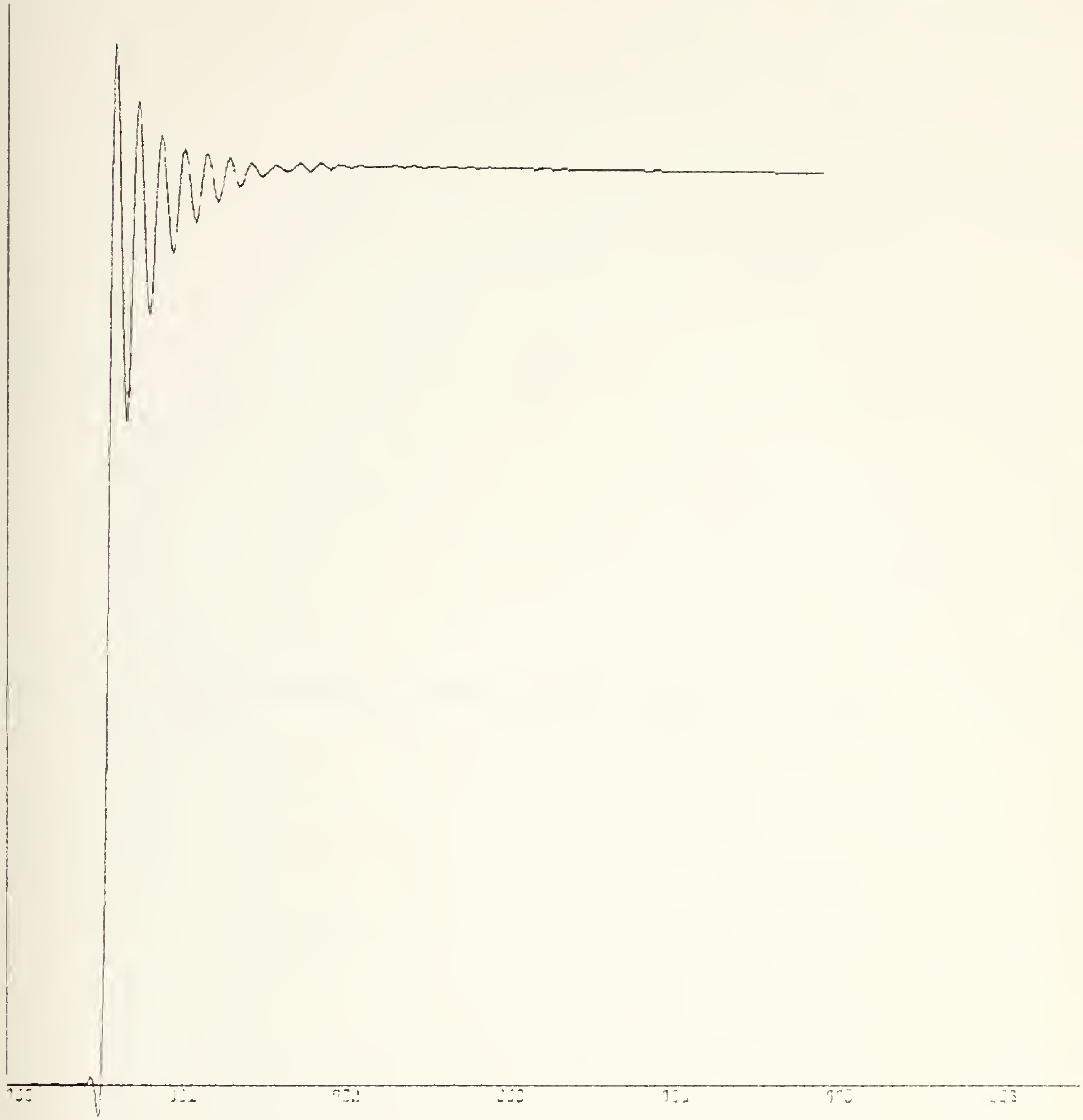
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT62 , TURN 20 KN.
PLØT IS ROLL RATE VERSUS TIME

PLOT 22

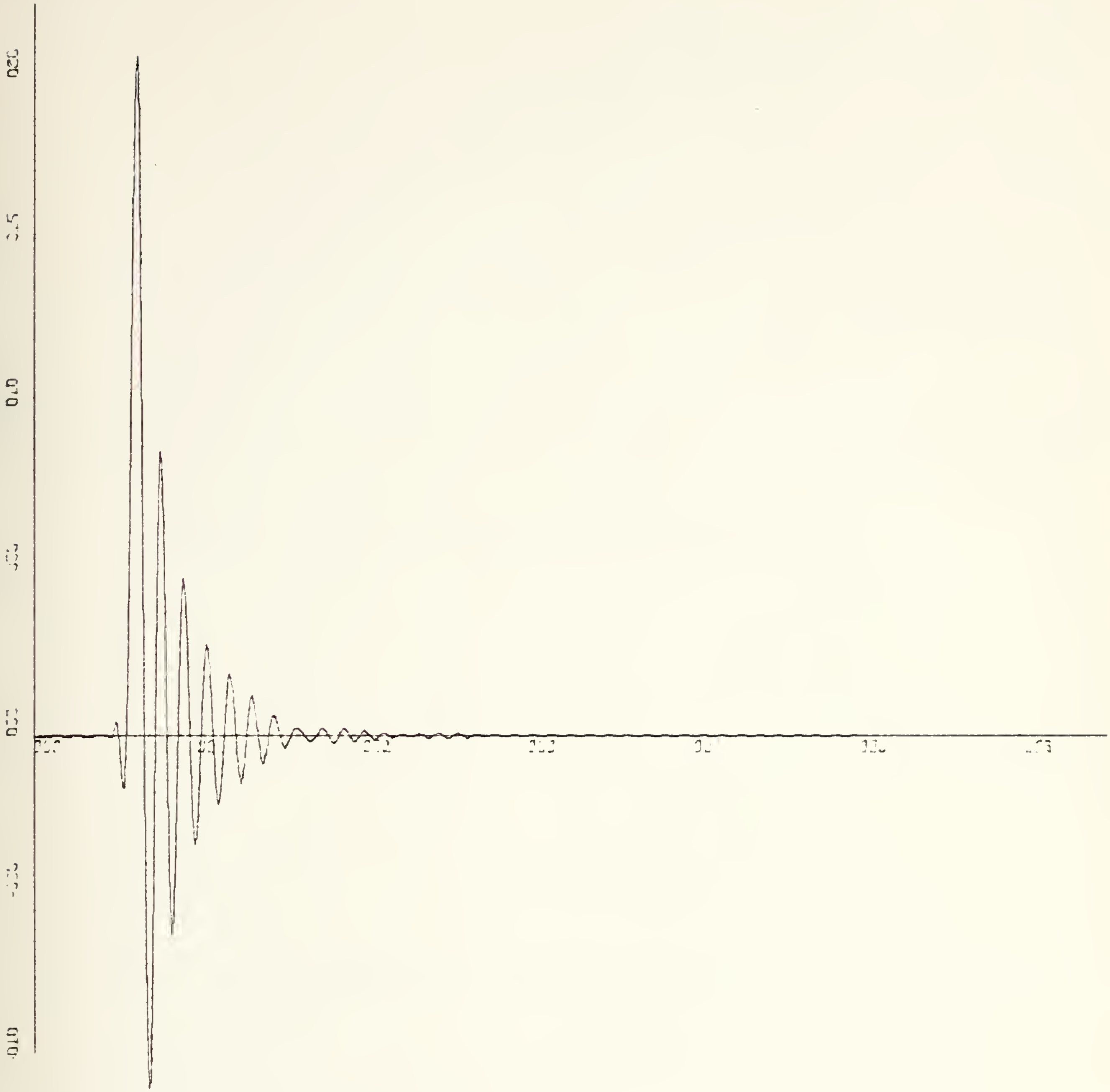
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
AGRT63 , TURN 20 KN.
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 23

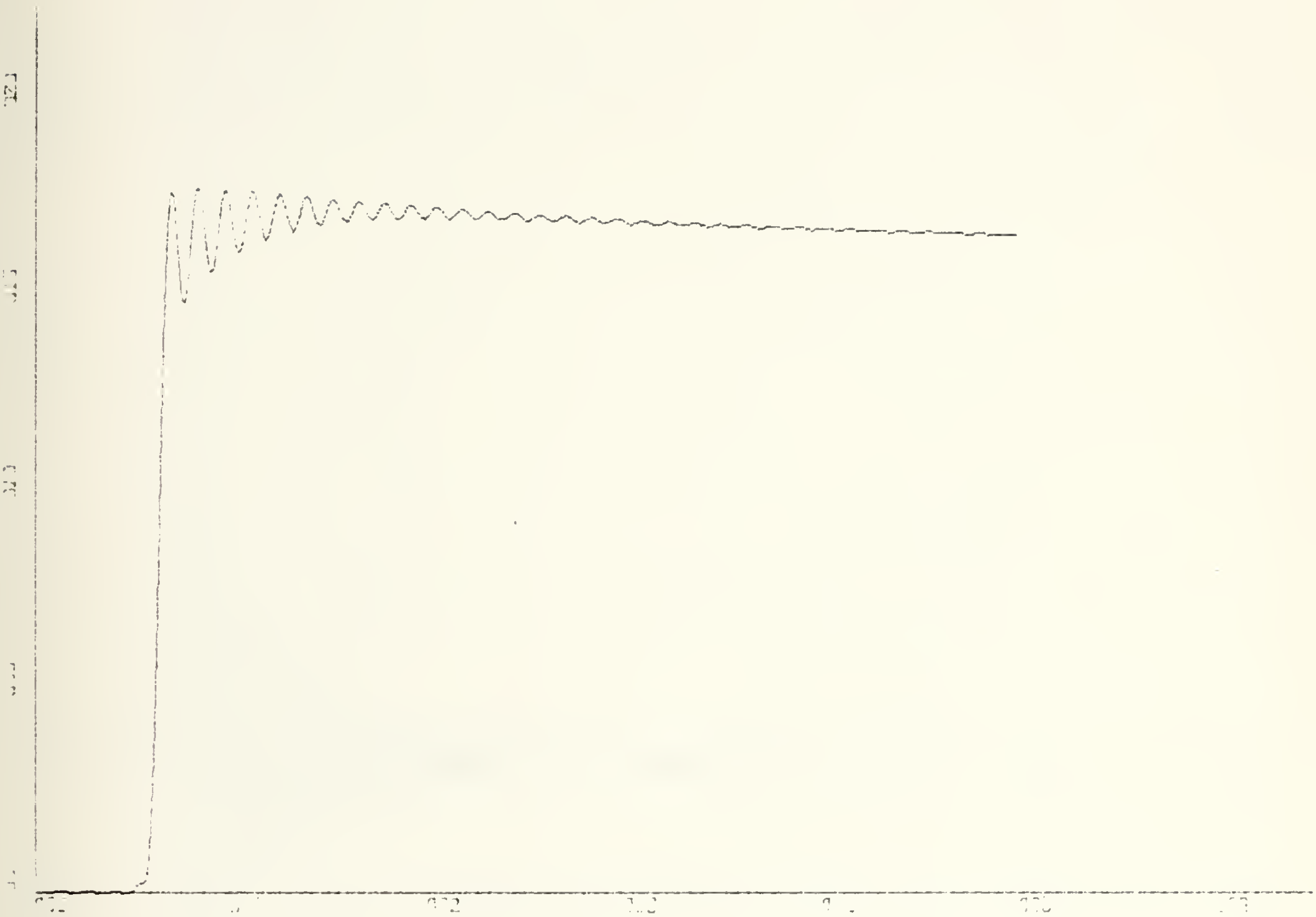
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
RGRT63 . TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 24

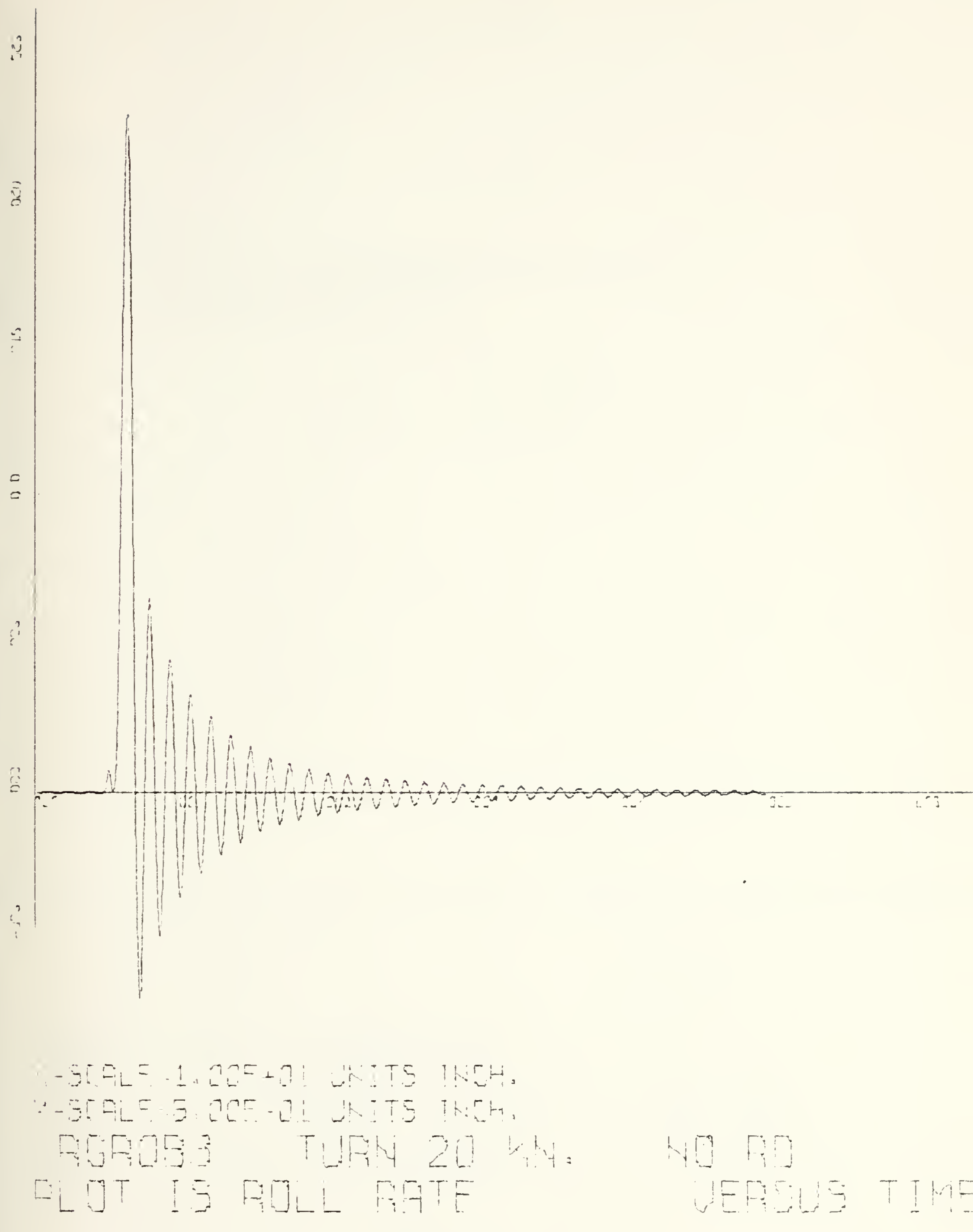
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
PGRDB3 - TURN 20 %, NO RD
PLOT IS ROLL ANGLE VERSUS TIME

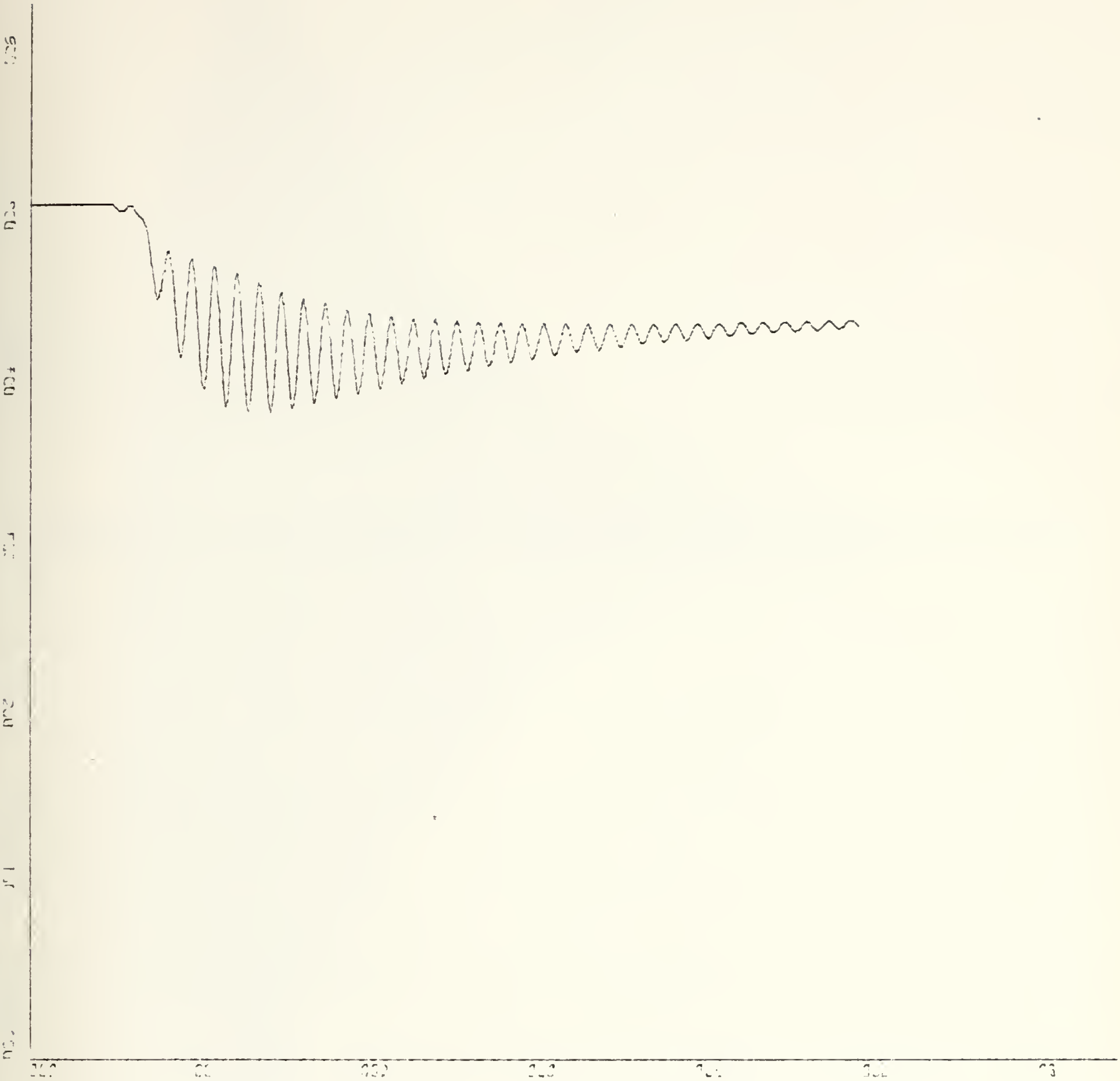
PLOT 25

for applied parameters, see first page of this appendix



PLOT 26

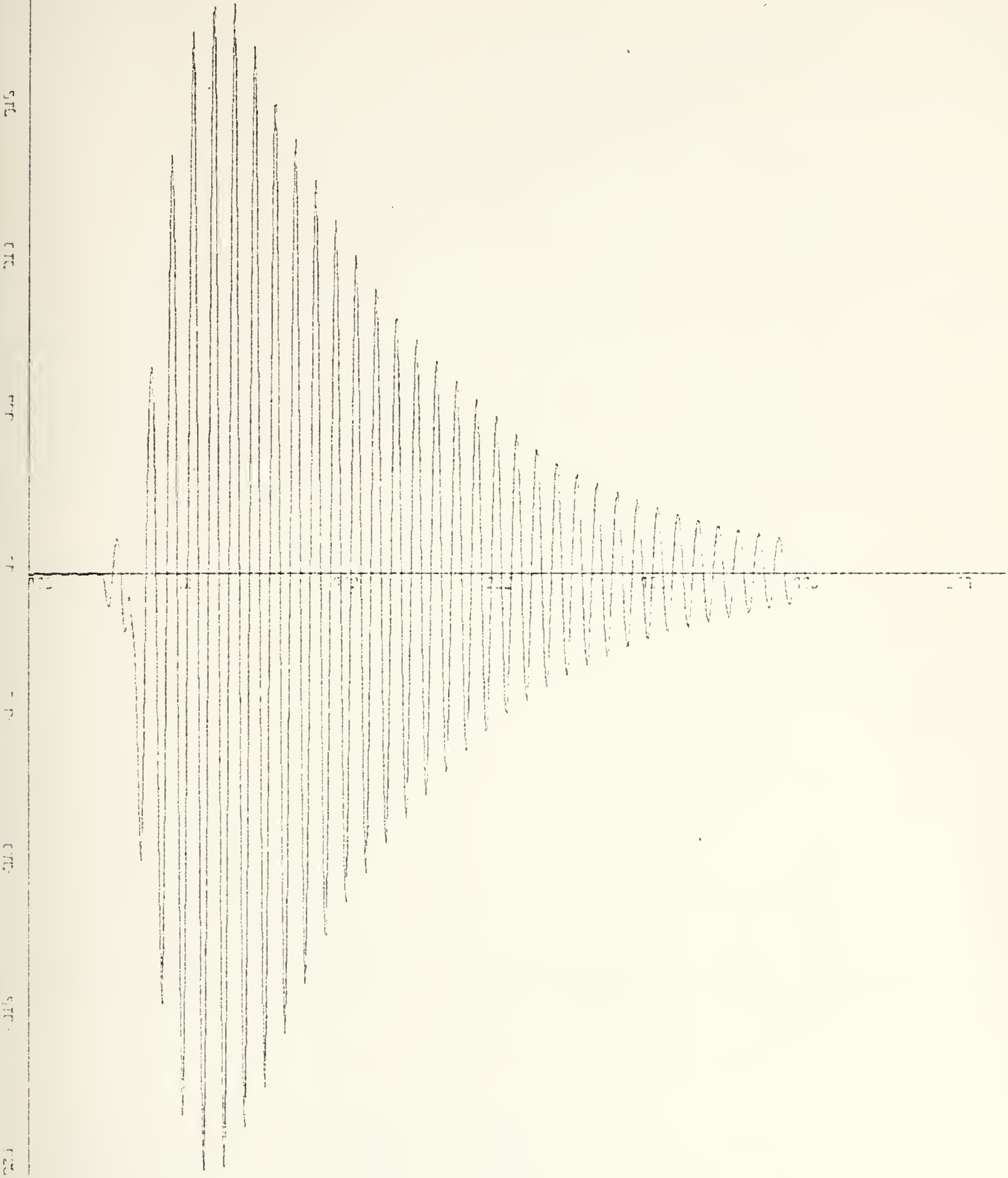
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 1.00E-01 UNITS INCH.
AGRO93 . TURN 20 KN. . NO AD
PLOT IS PITCH ANGLE VERSUS TIME

PLOT 27

for applied parameters see first page of this appendix

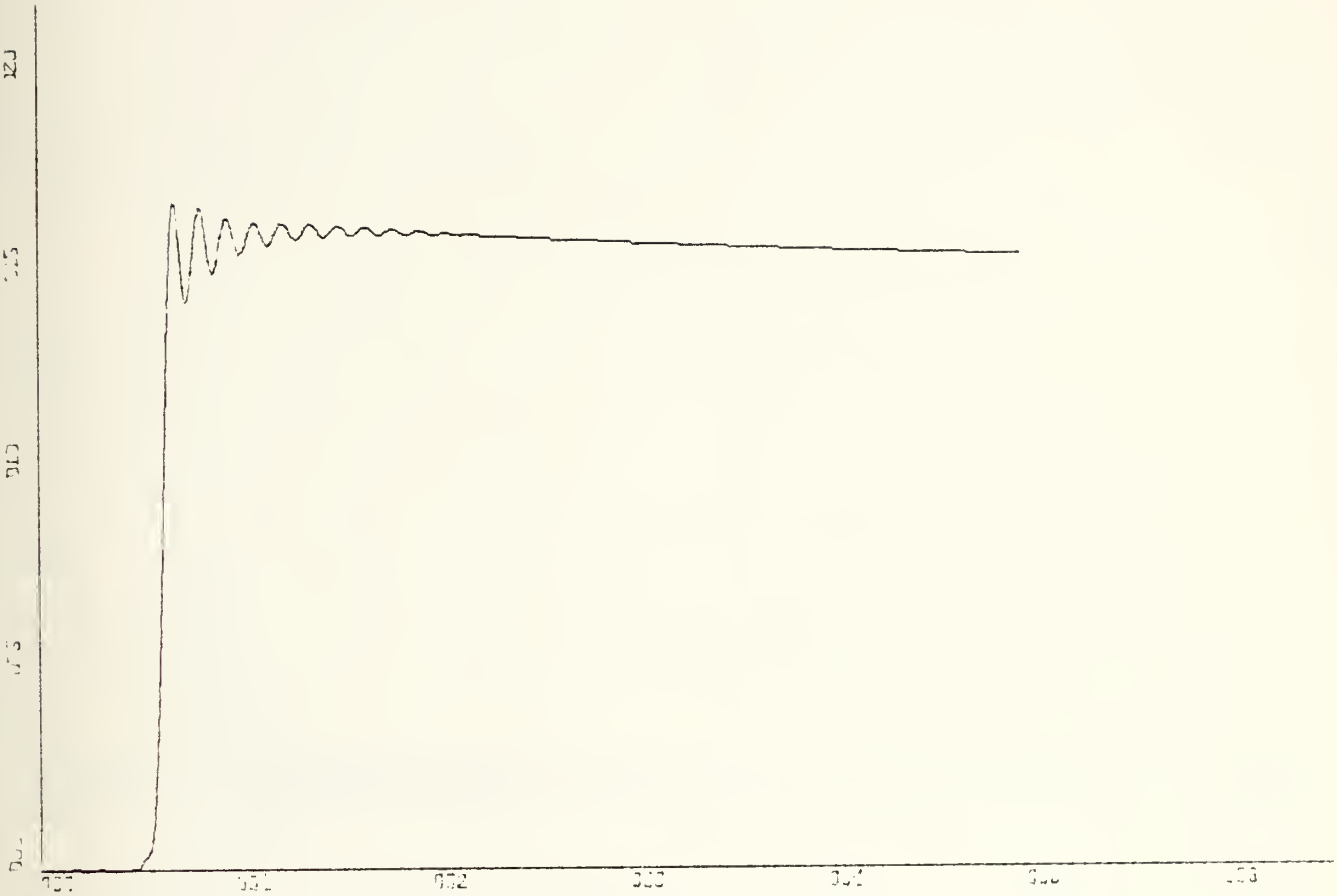


PLOT IS PITCH RATE VERSUS TIME

X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-02 UNITS INCH.

PLOT 28

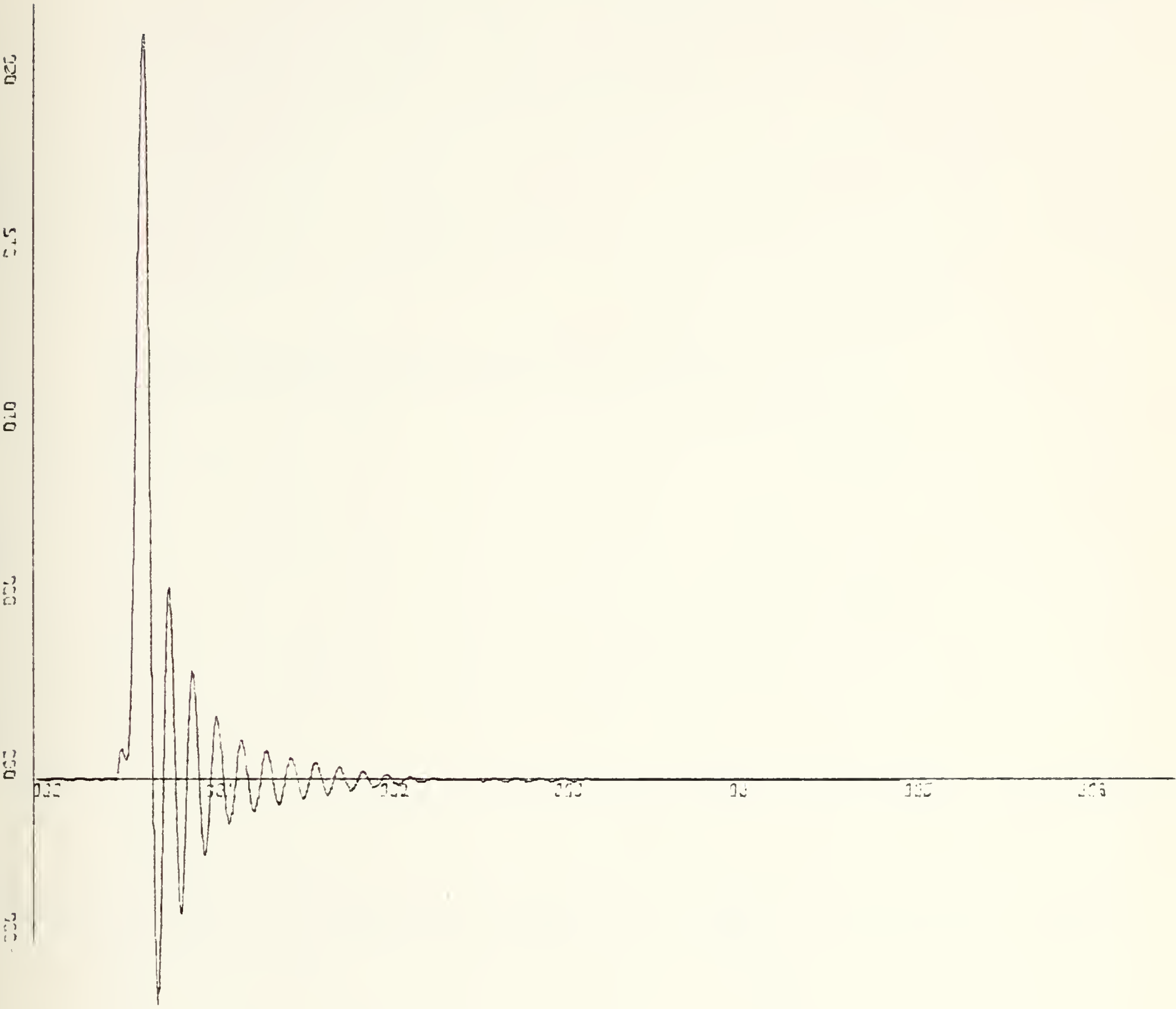
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT81 , TURN 20 KN.
PLØT IS RØLL ANGLE VERSUS TIME

PLOT 29

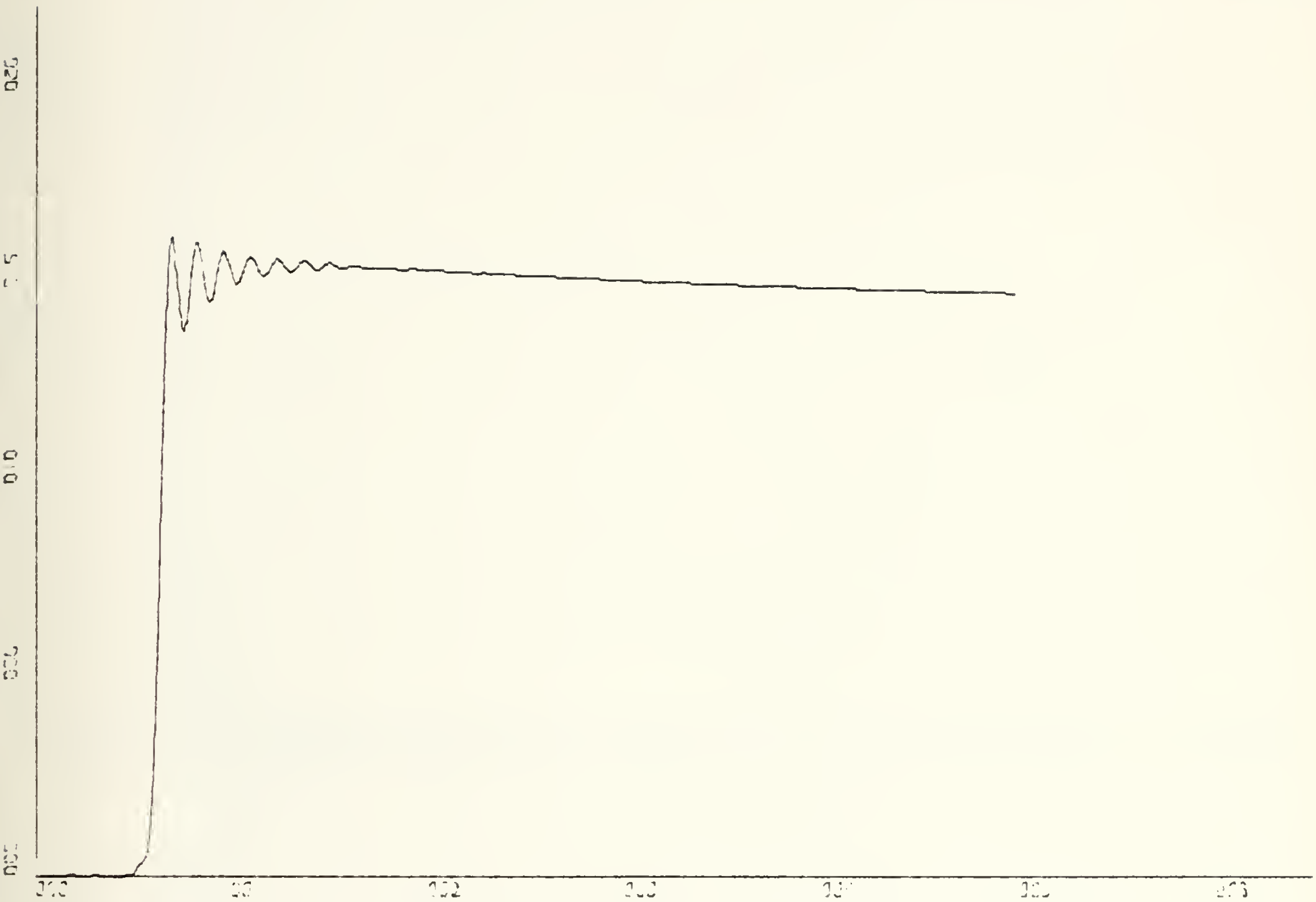
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT81 . TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 30

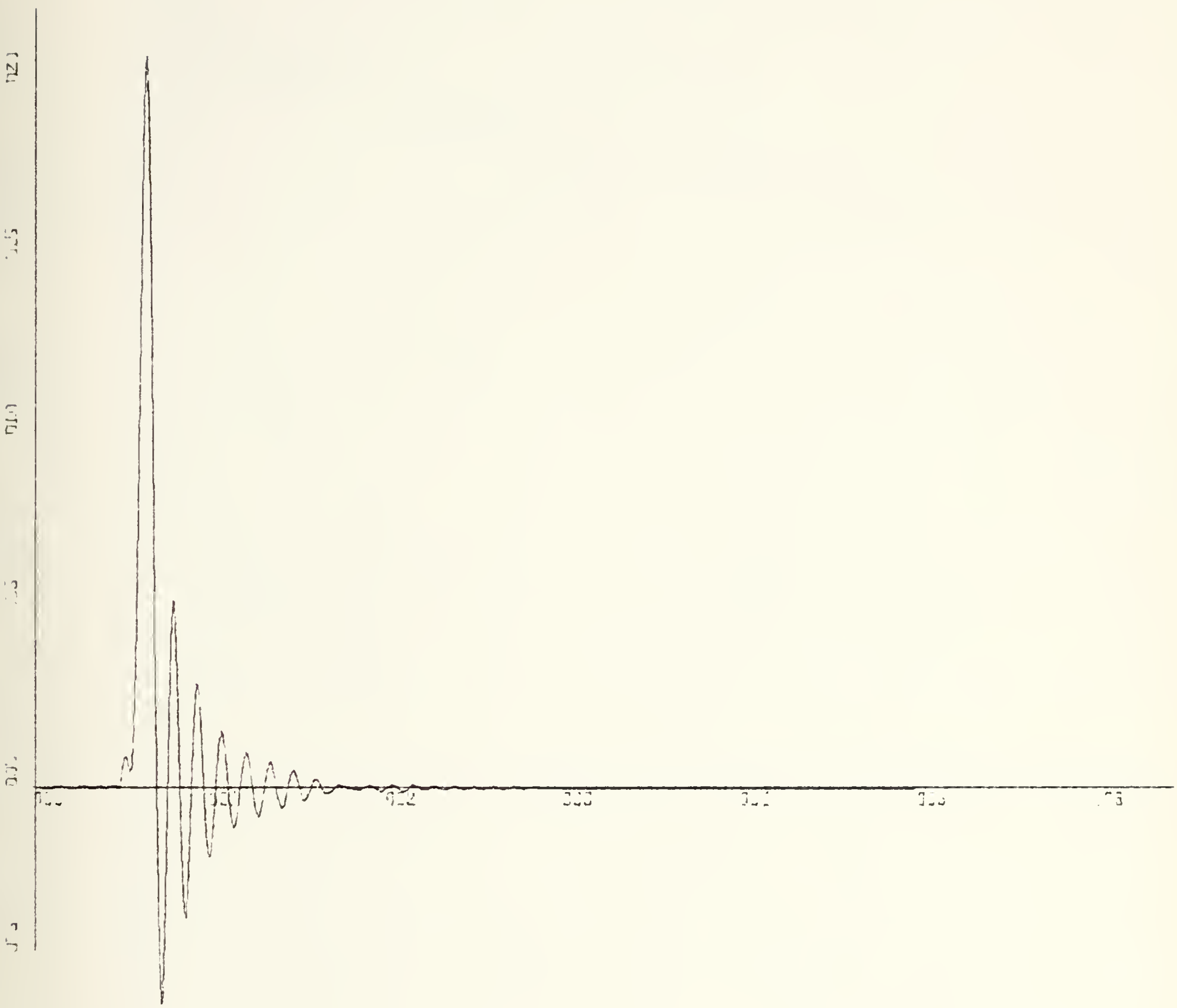
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
RGRT82 , TURN 20 KN.
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 31

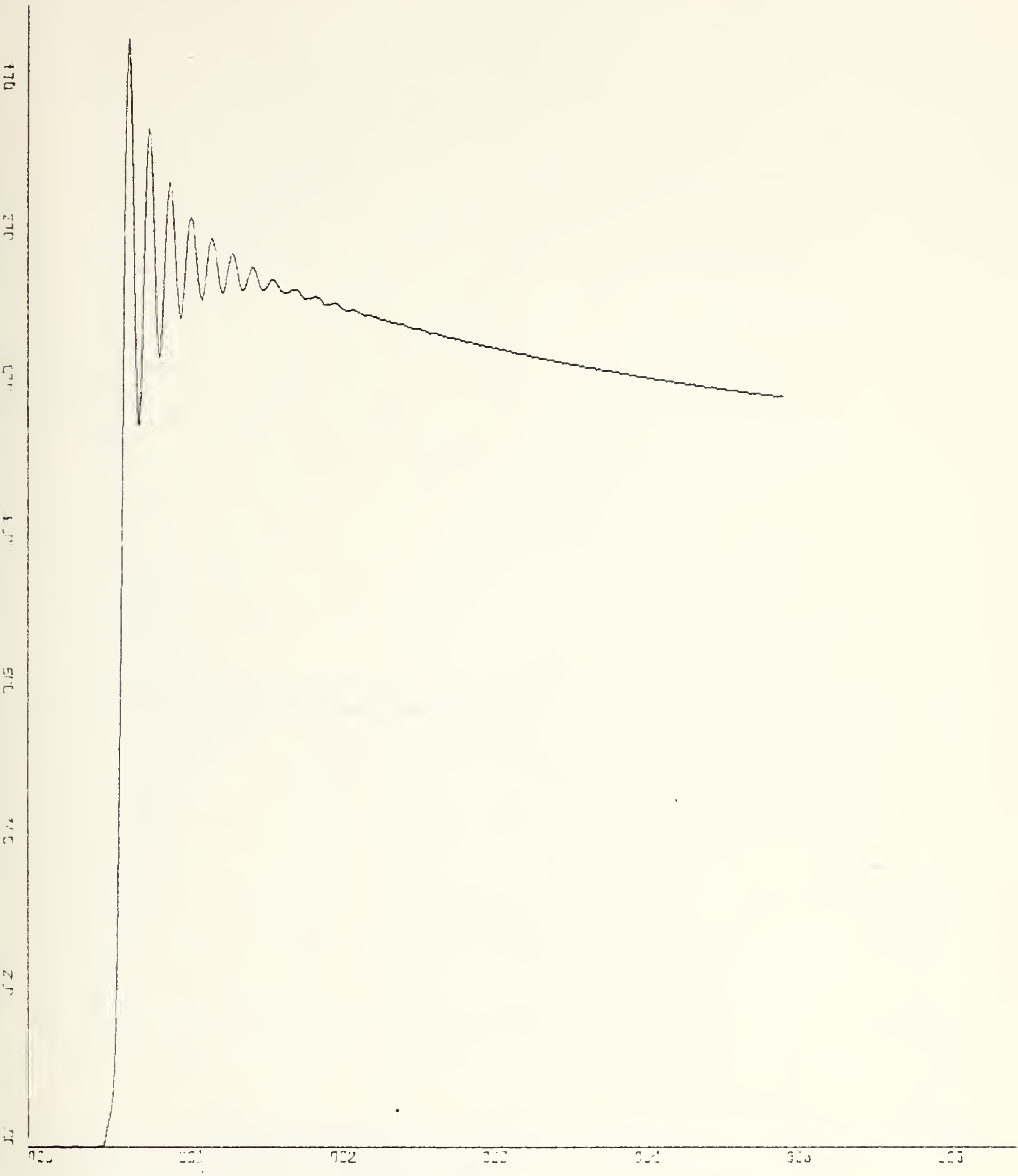
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT82 , TURN 20 KN.
PLØT IS RØLL RATE VERSUS TIME

PLOT 32

for applied parameters see first page of this appendix

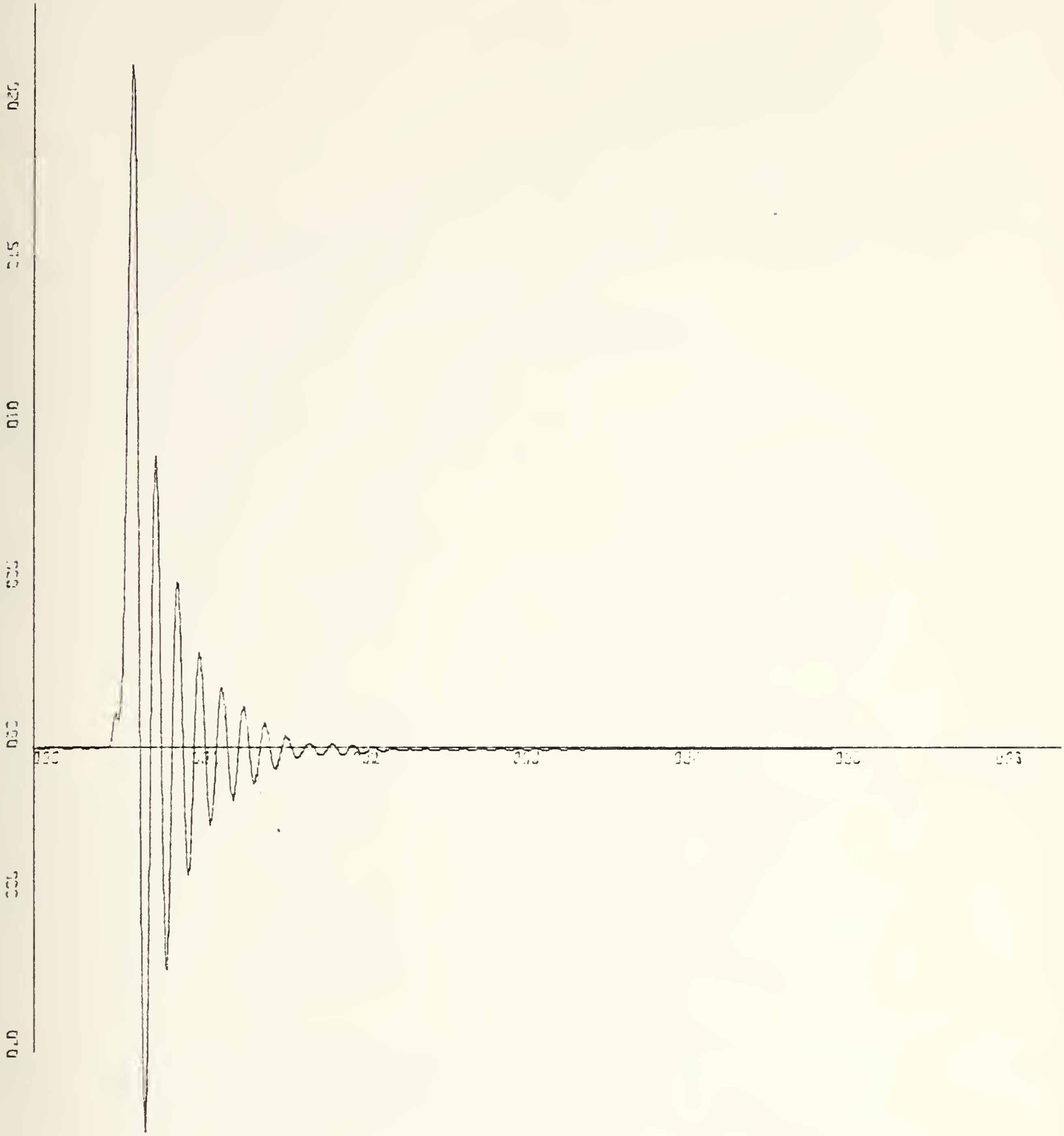


PLØT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 33

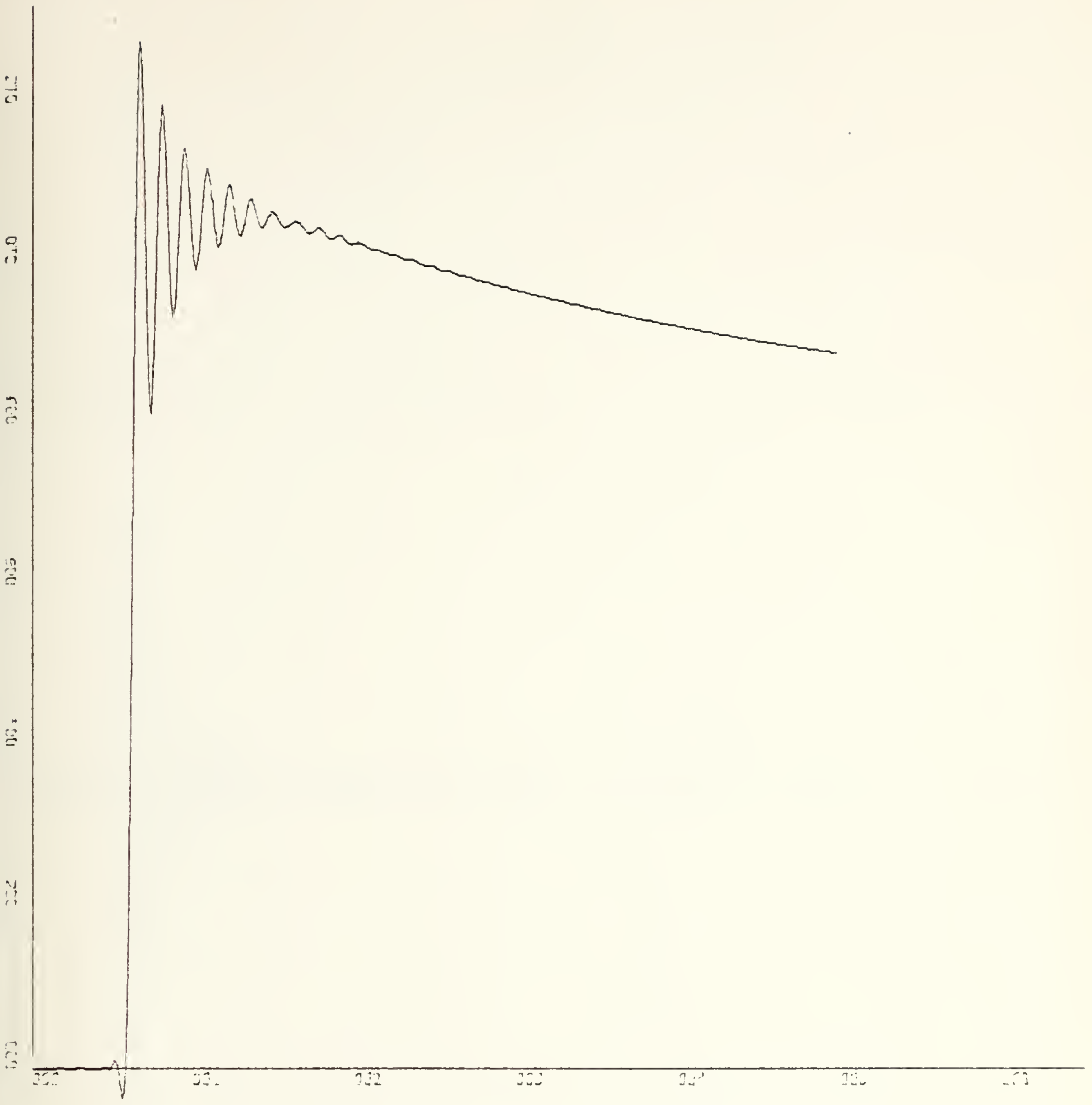
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RCRTX1 . TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 34

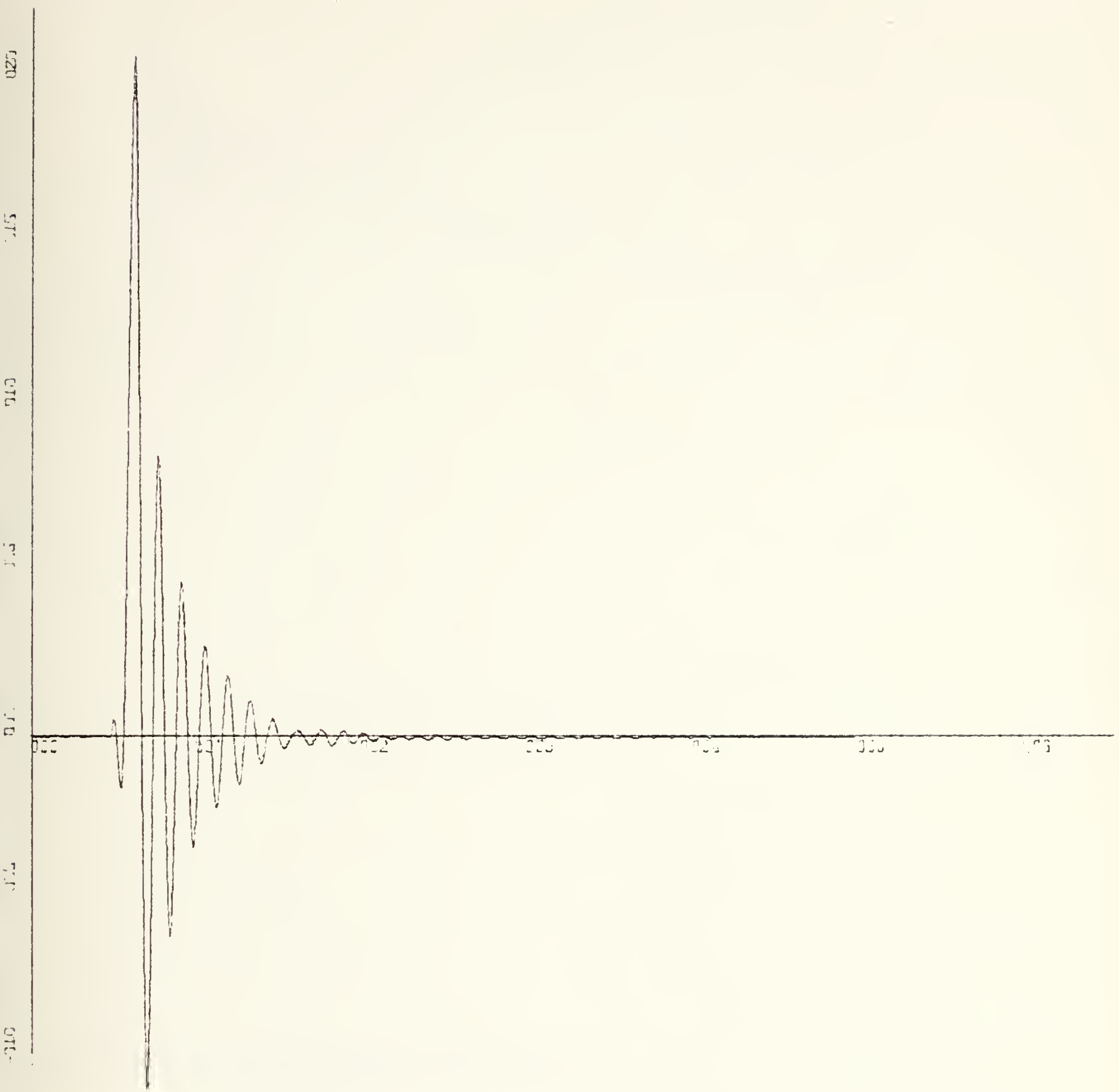
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS/INCH.
Y-SCALE=2.00E-01 UNITS/INCH.
RGRTX2 , TURN 20 KN.
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 35

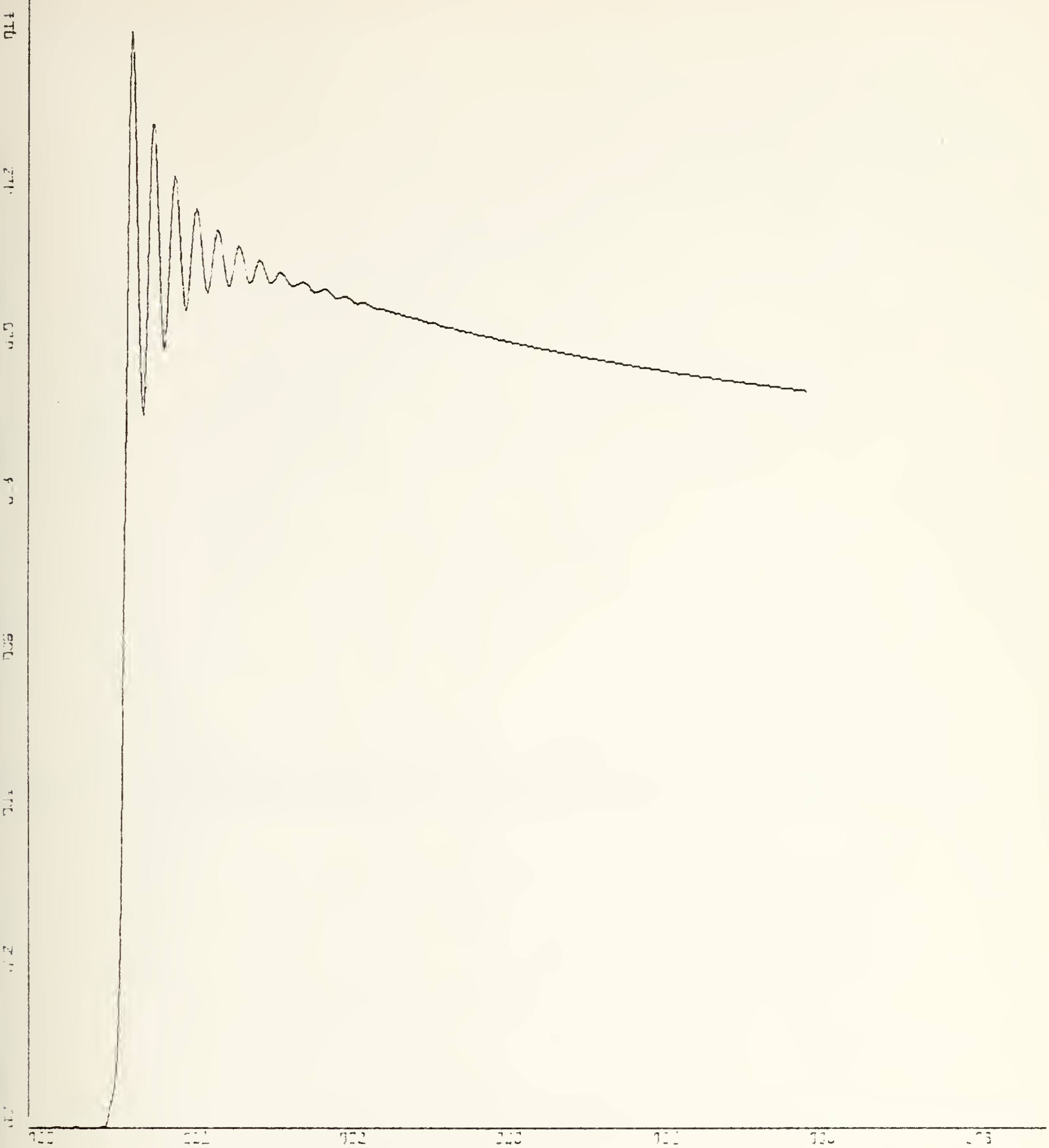
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRTX2 , TURN 20 KN.
PLØT IS RØLL RATE VERSUS TIME

PLOT 36

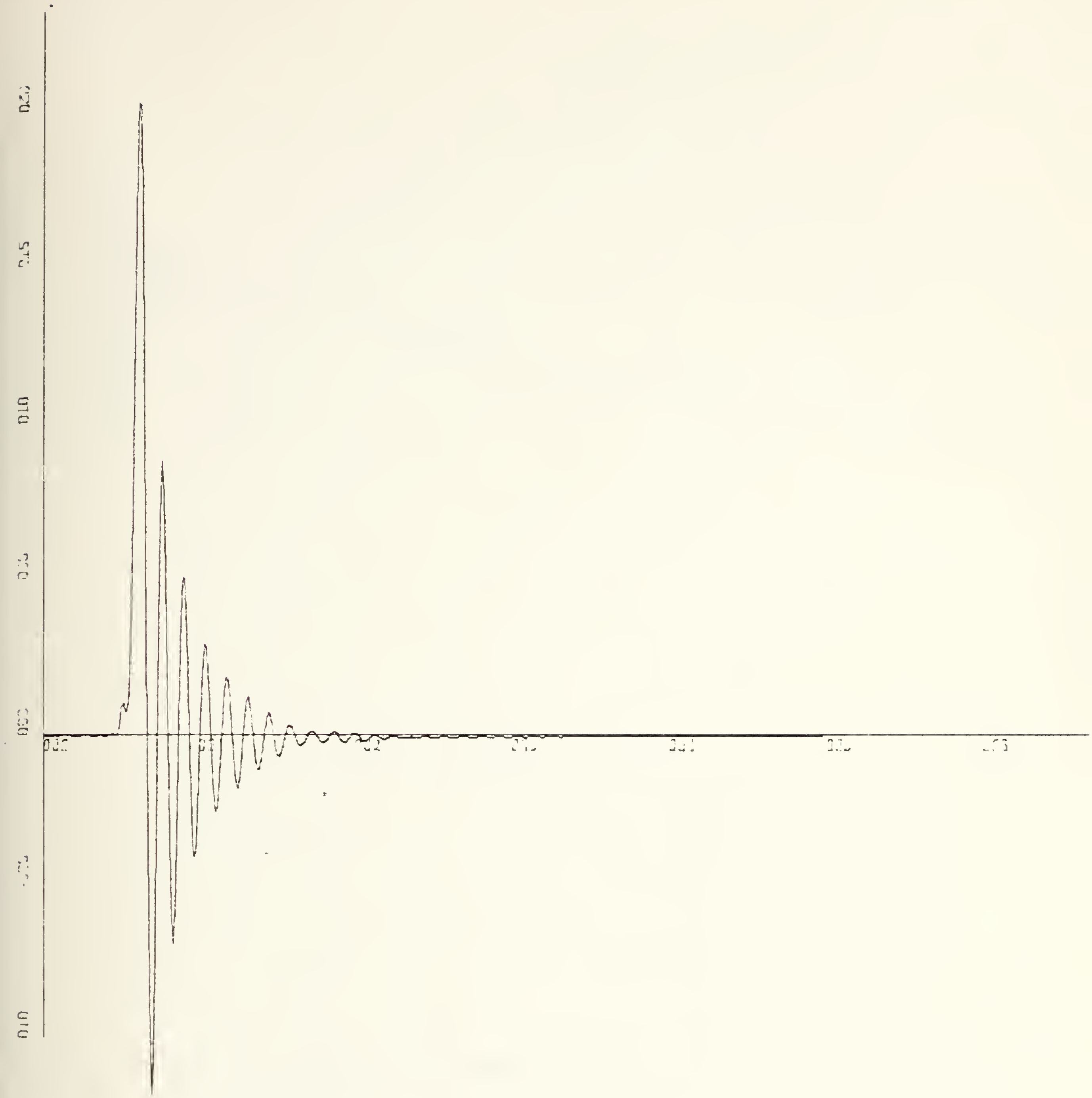
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 2.00E-01 UNITS INCH.
RGRTX3 . TURN 20 KN.
PLØT IS ROLL ANGLE VERSUS TIME

PLOT 37

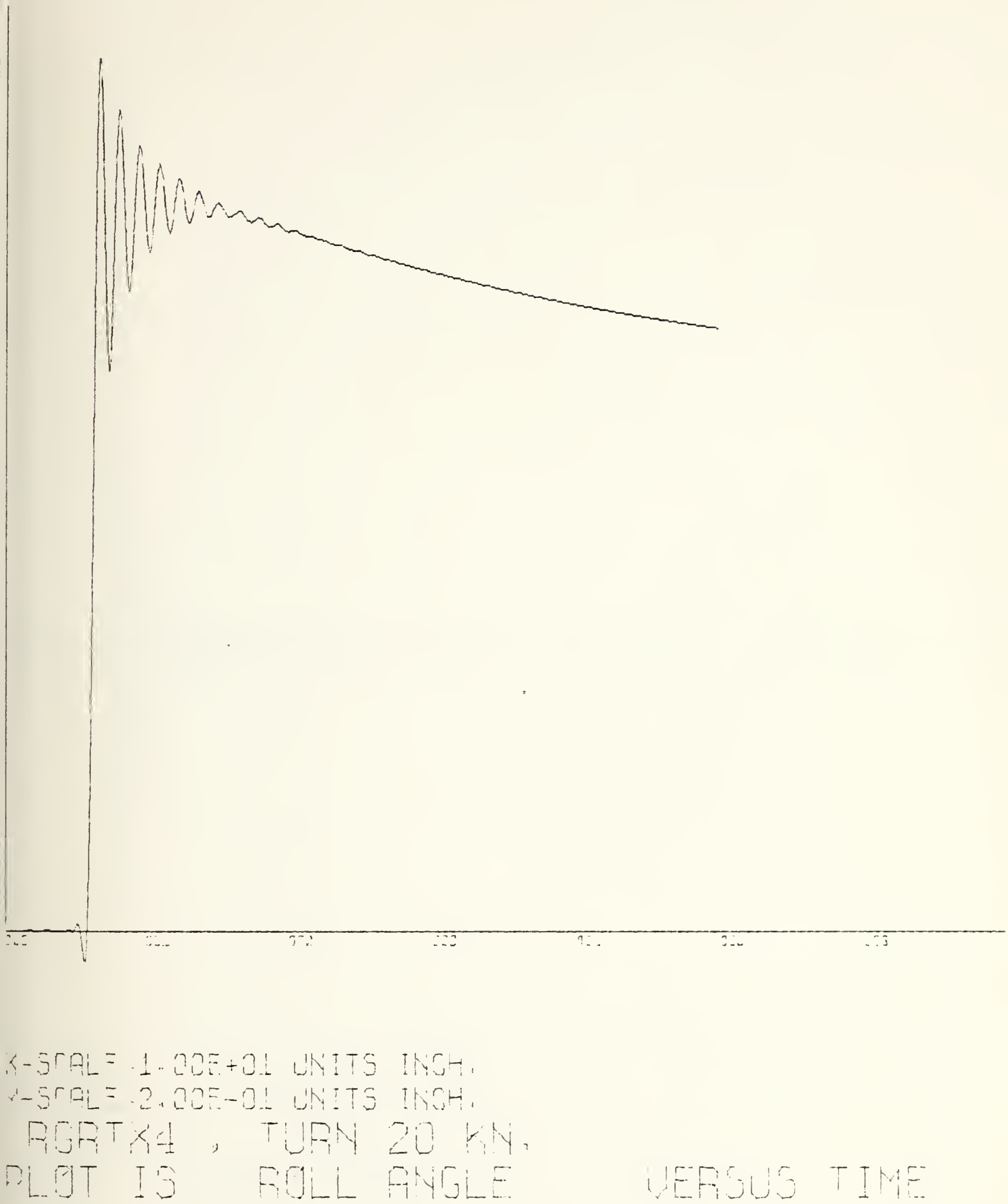
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRTX3 , TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

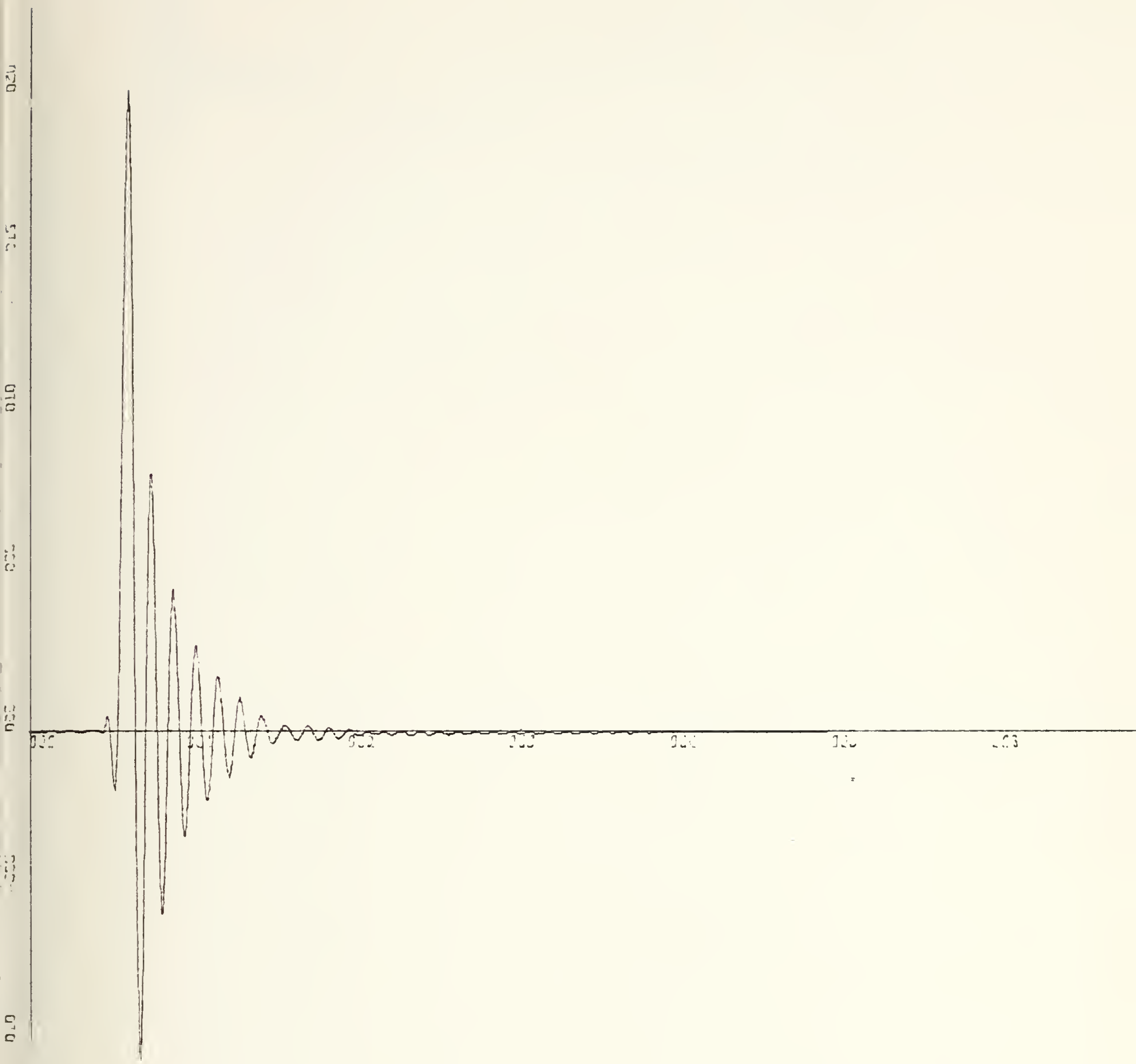
PLOT 38

for applied parameters see first page of this appendix



PLOT 39

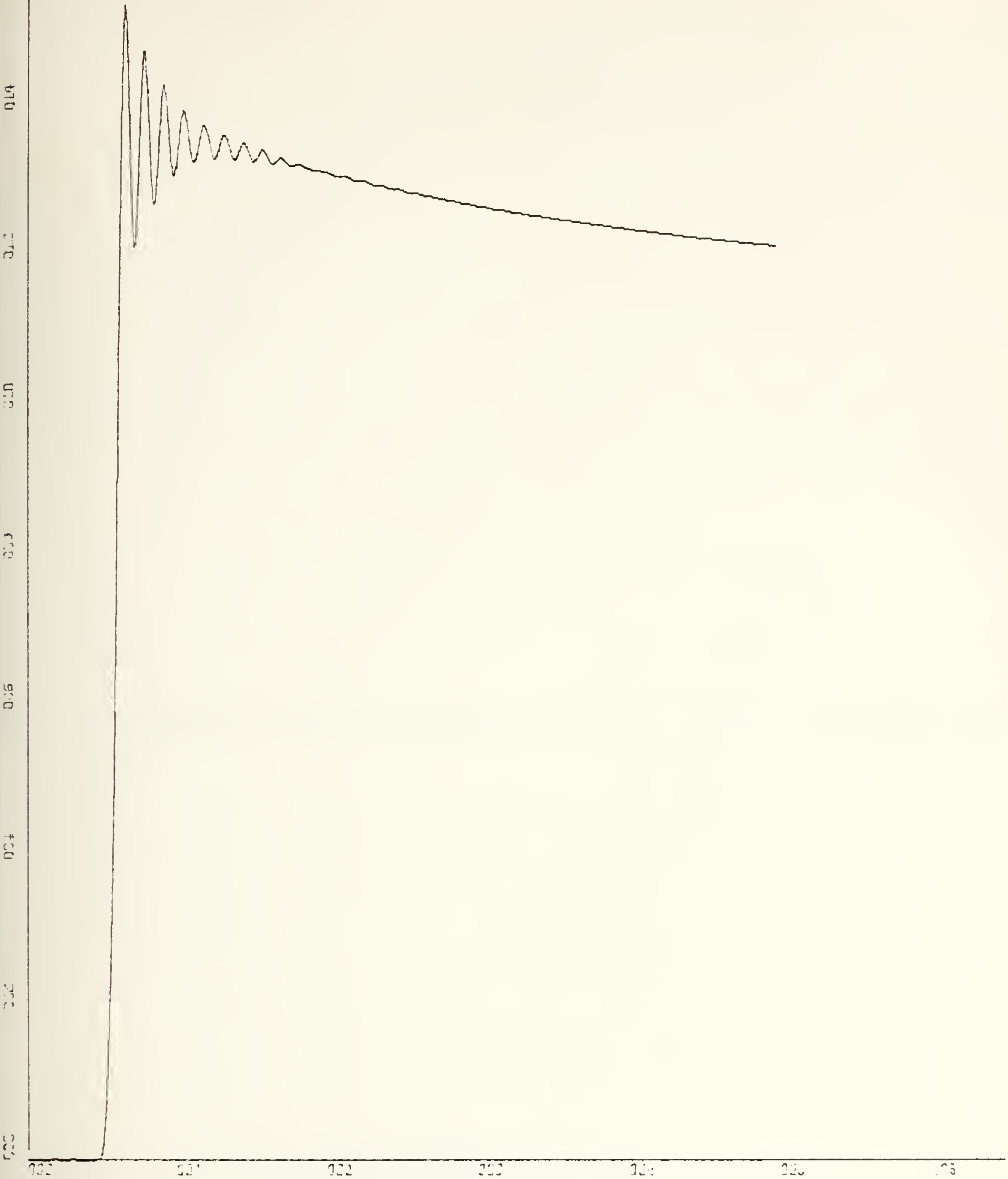
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRTX4 , TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 40

for applied parameters see first page of this appendix

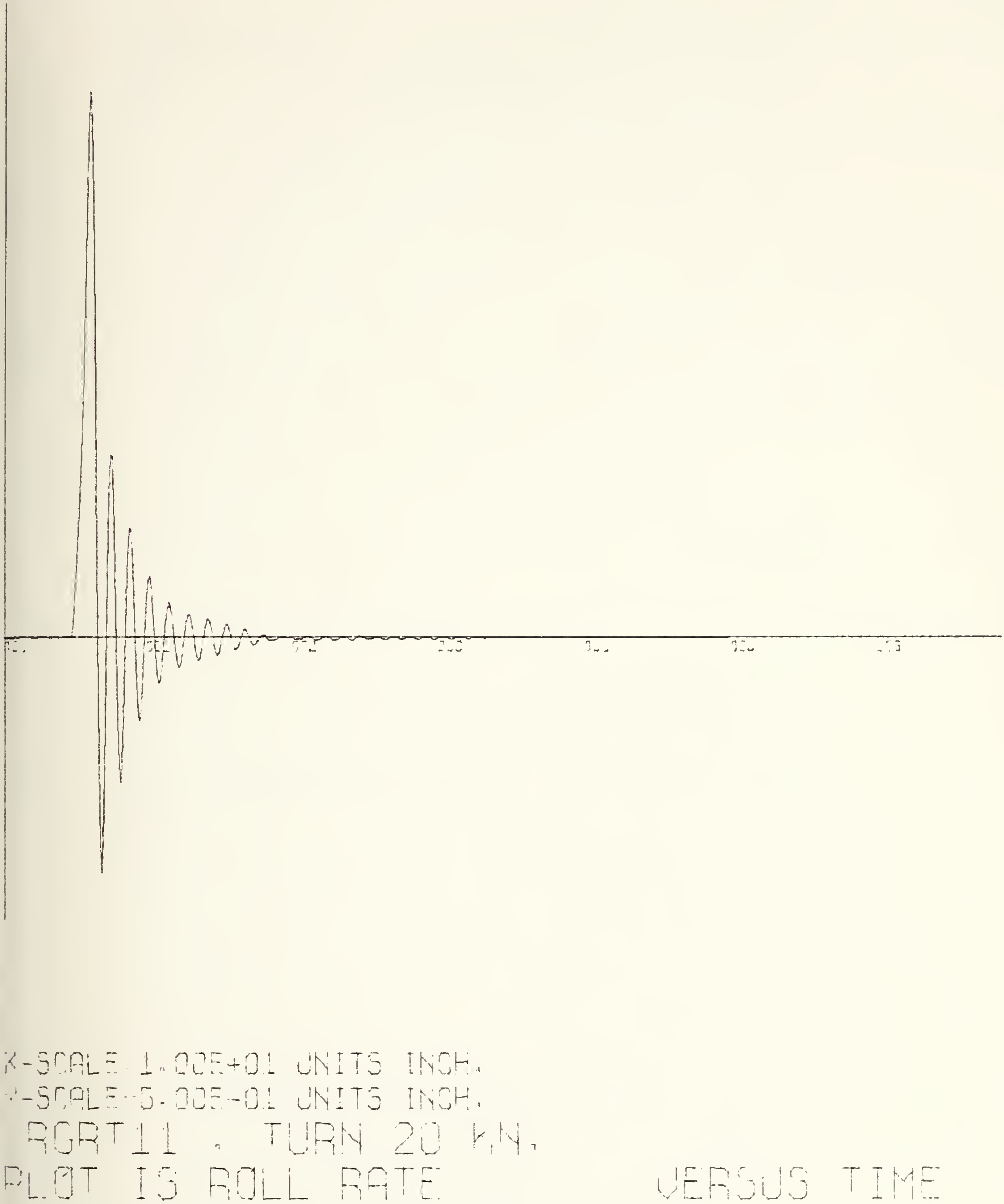


PLØT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

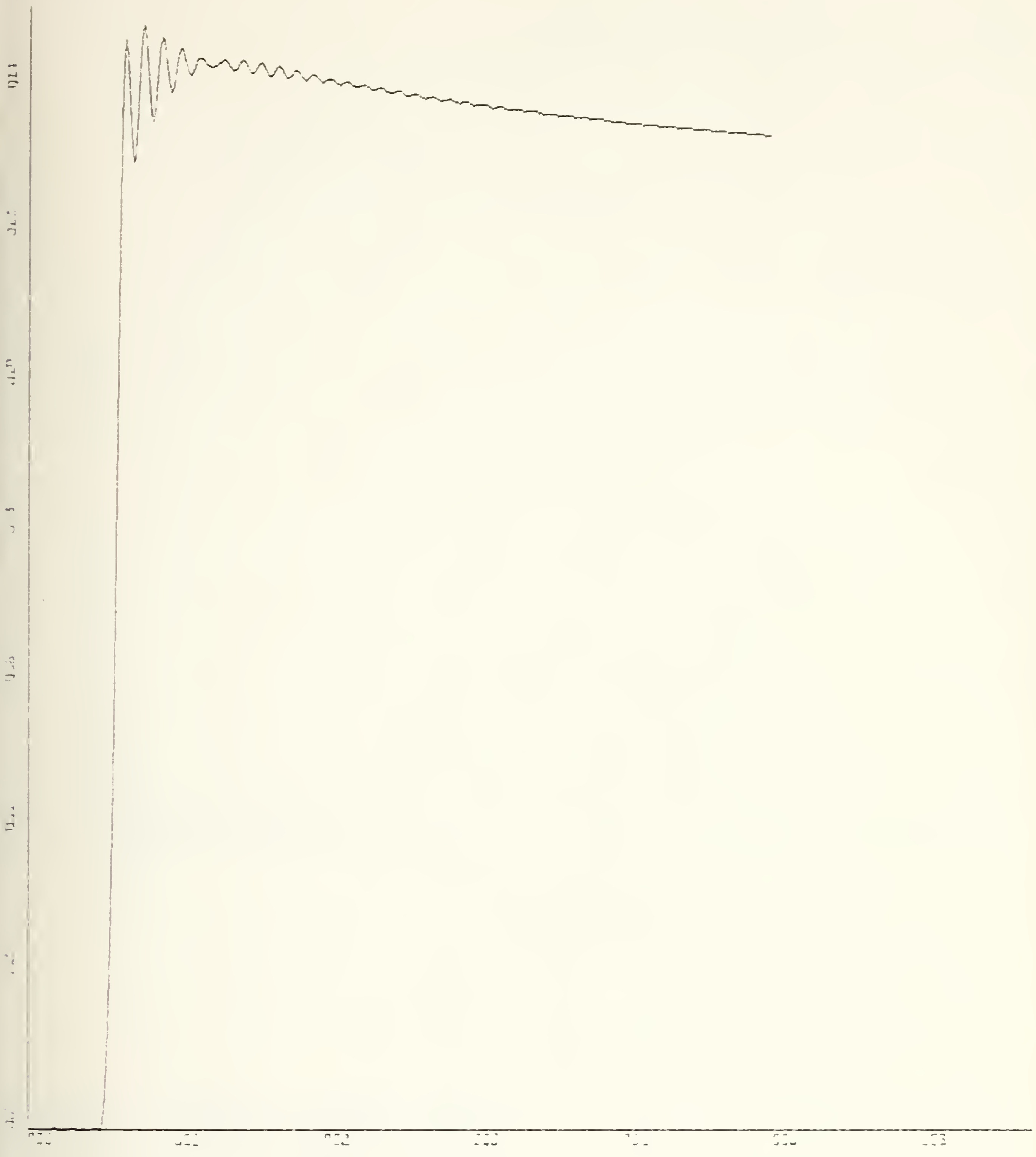
PLOT 41

for applied parameters see first page of this appendix



PLOT 42

for applied parameters see first page of this appendix

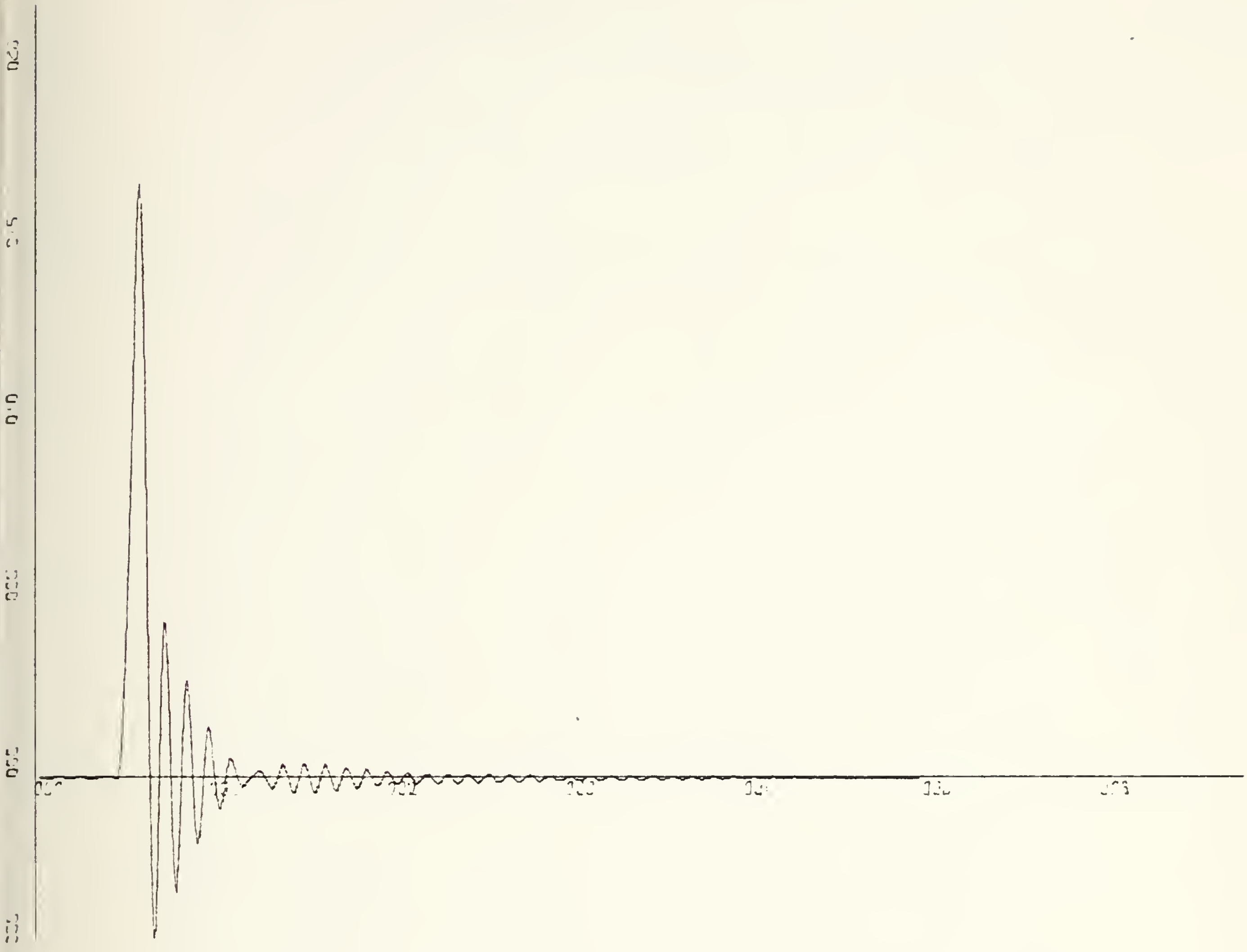


PLØT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 43

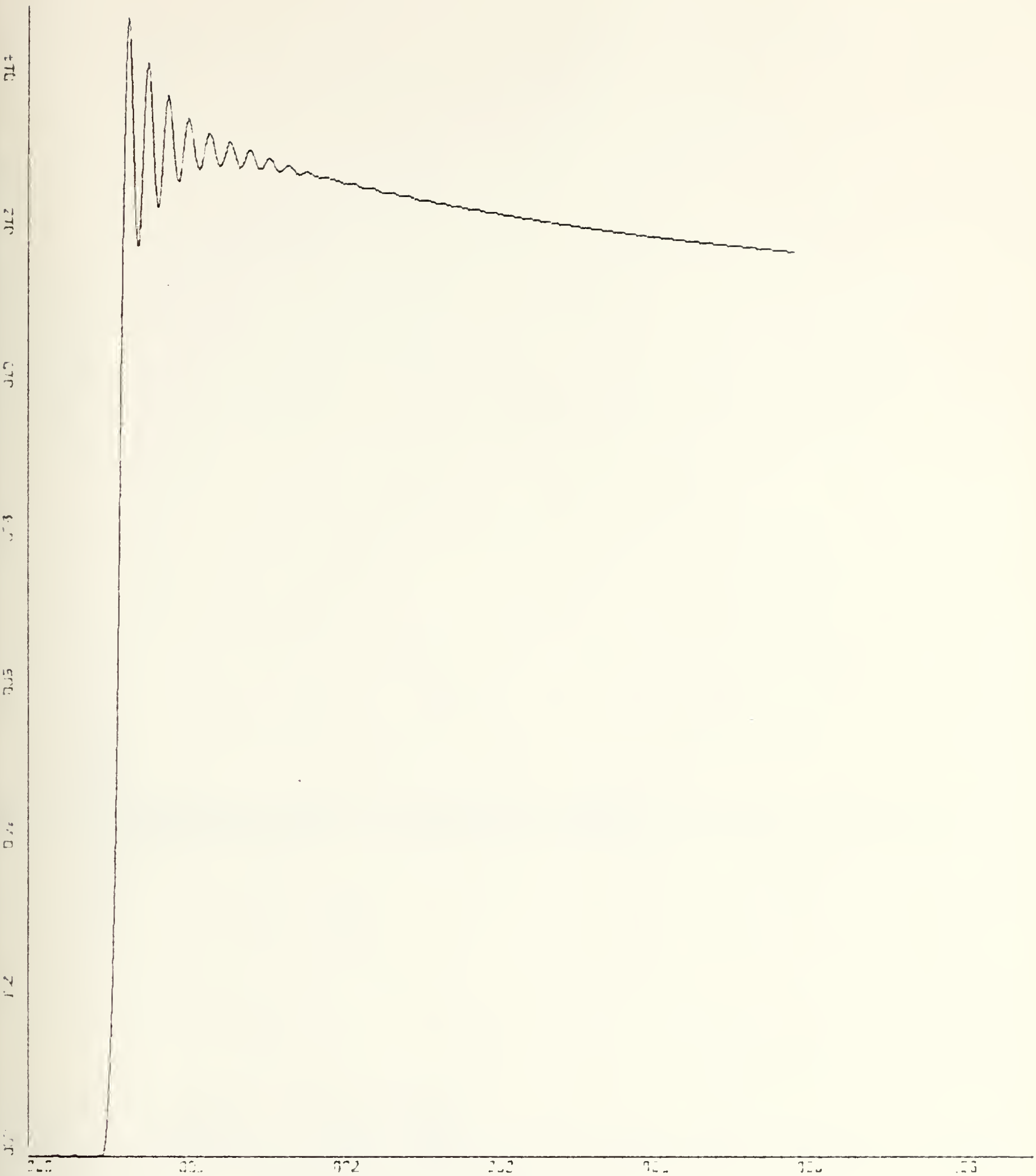
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
AGRT12 , TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 44

for applied parameters see first page of this appendix

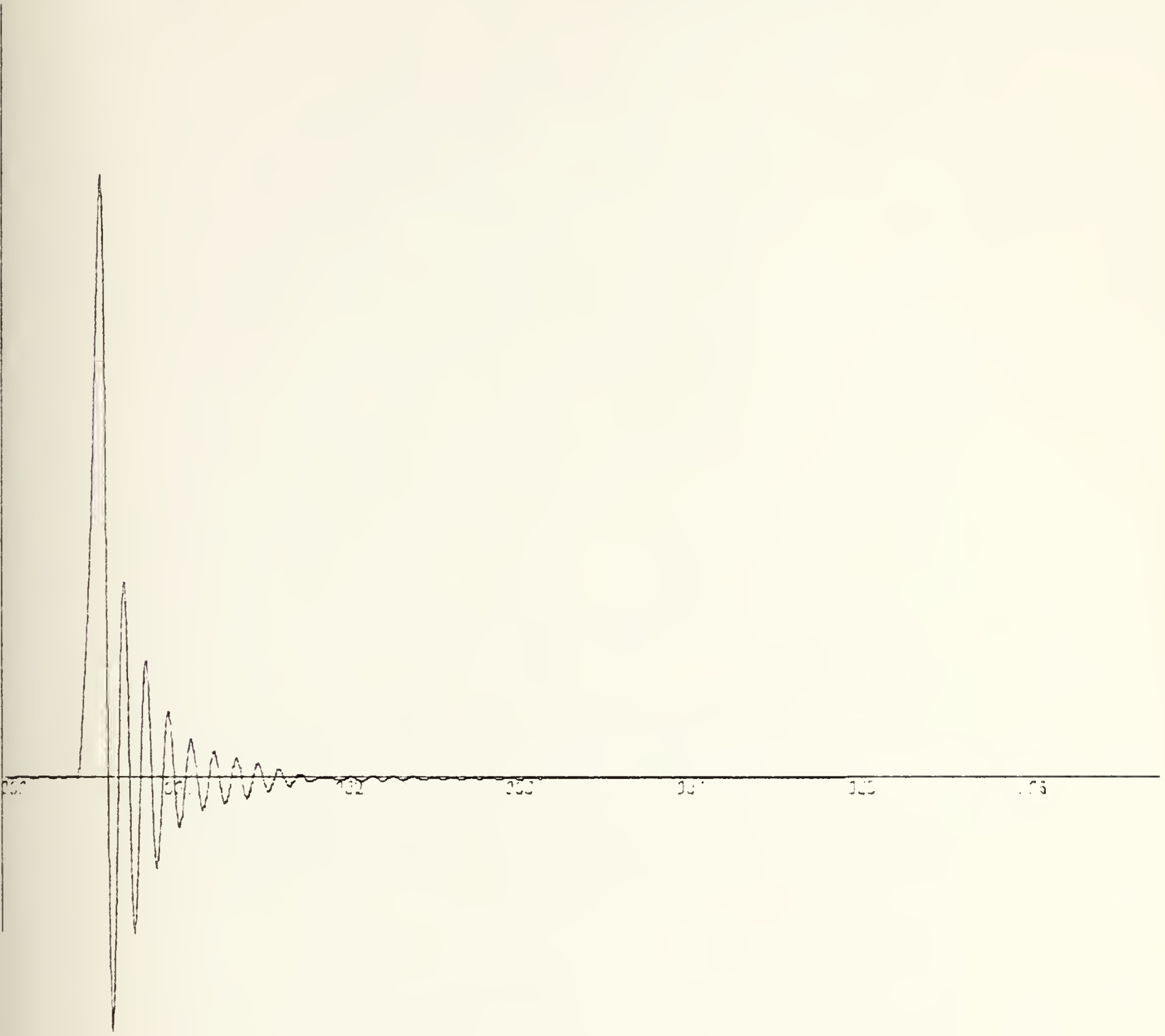


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 45

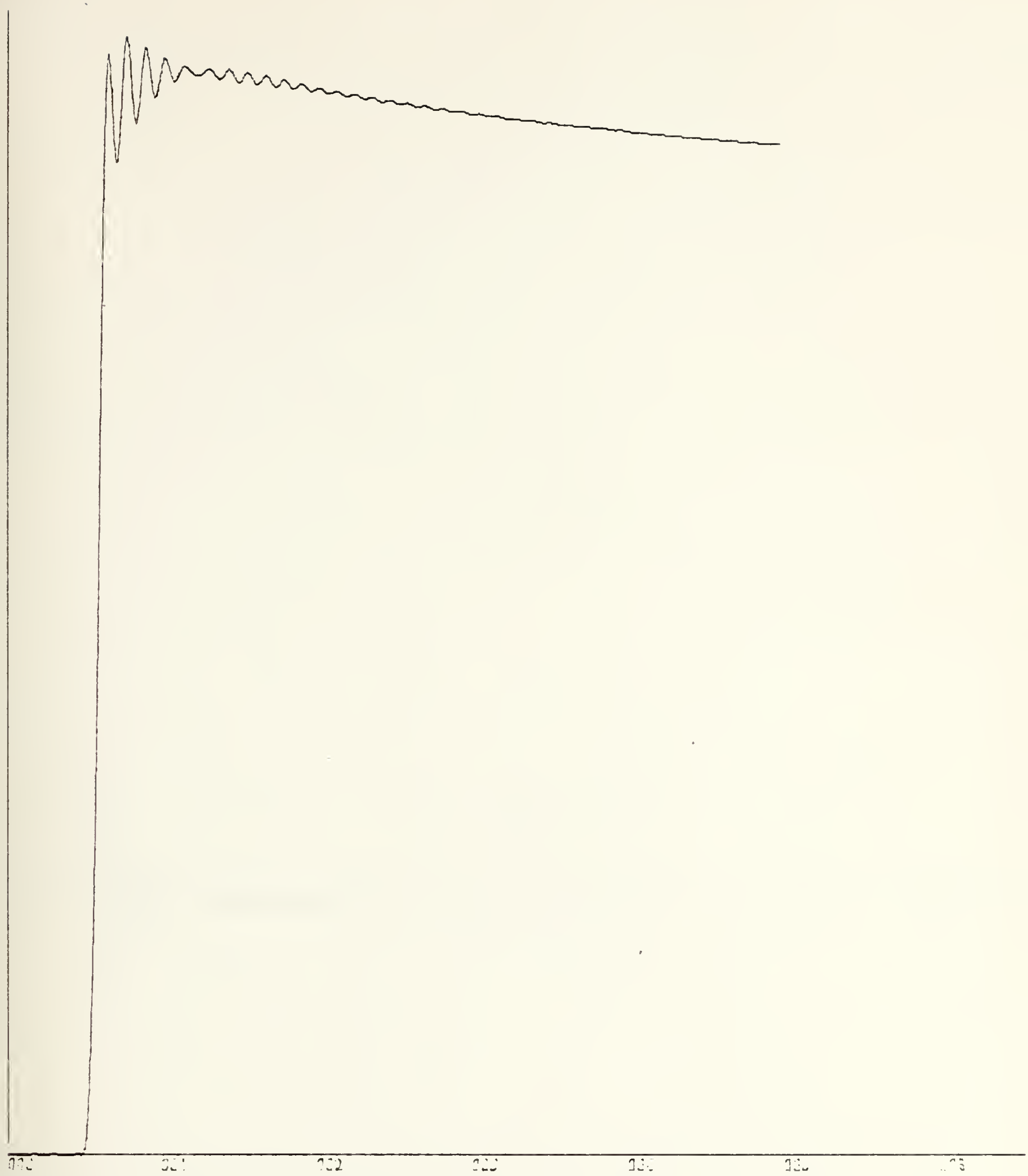
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRT13 , TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 46

for applied parameters see first page of this appendix

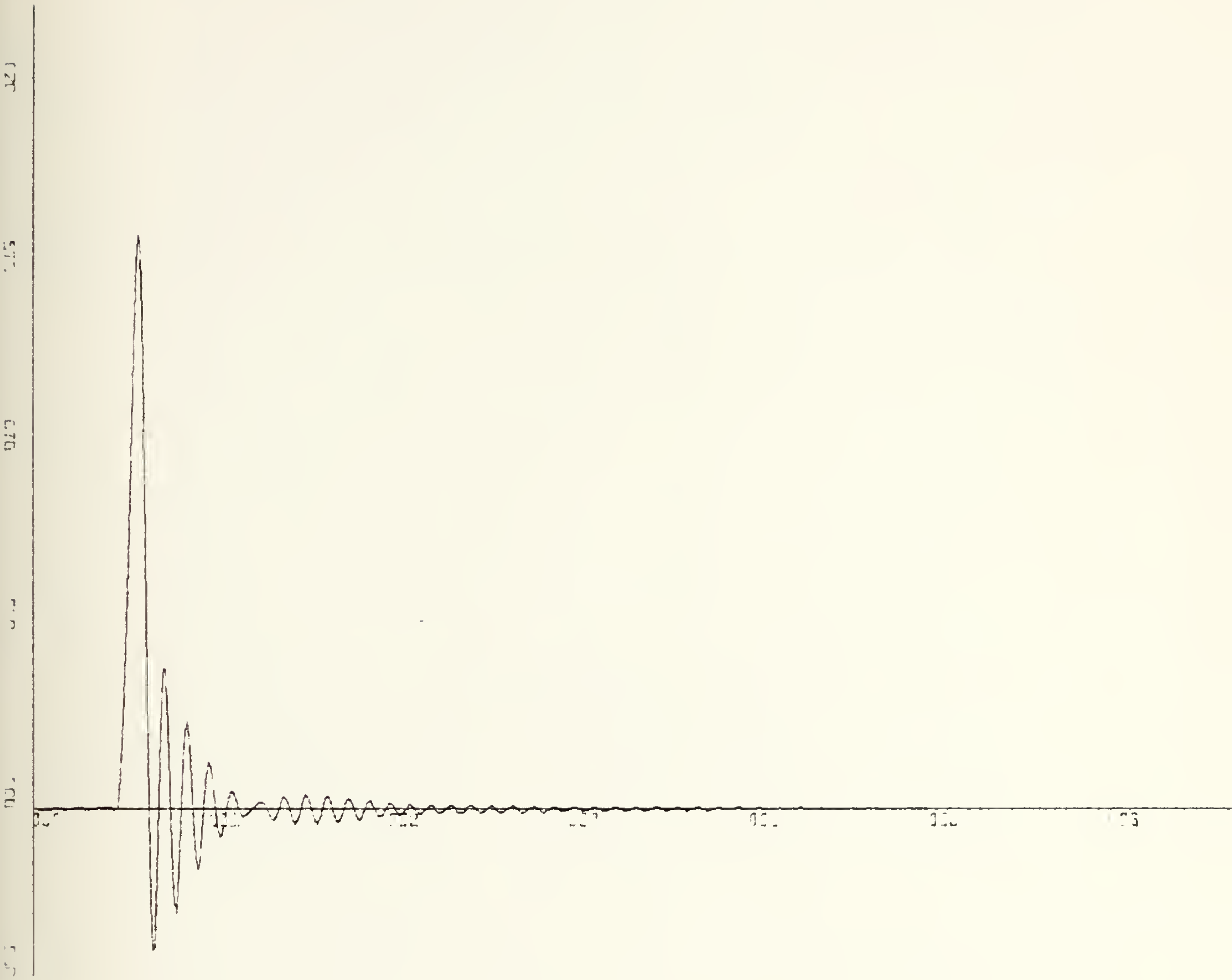


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 47

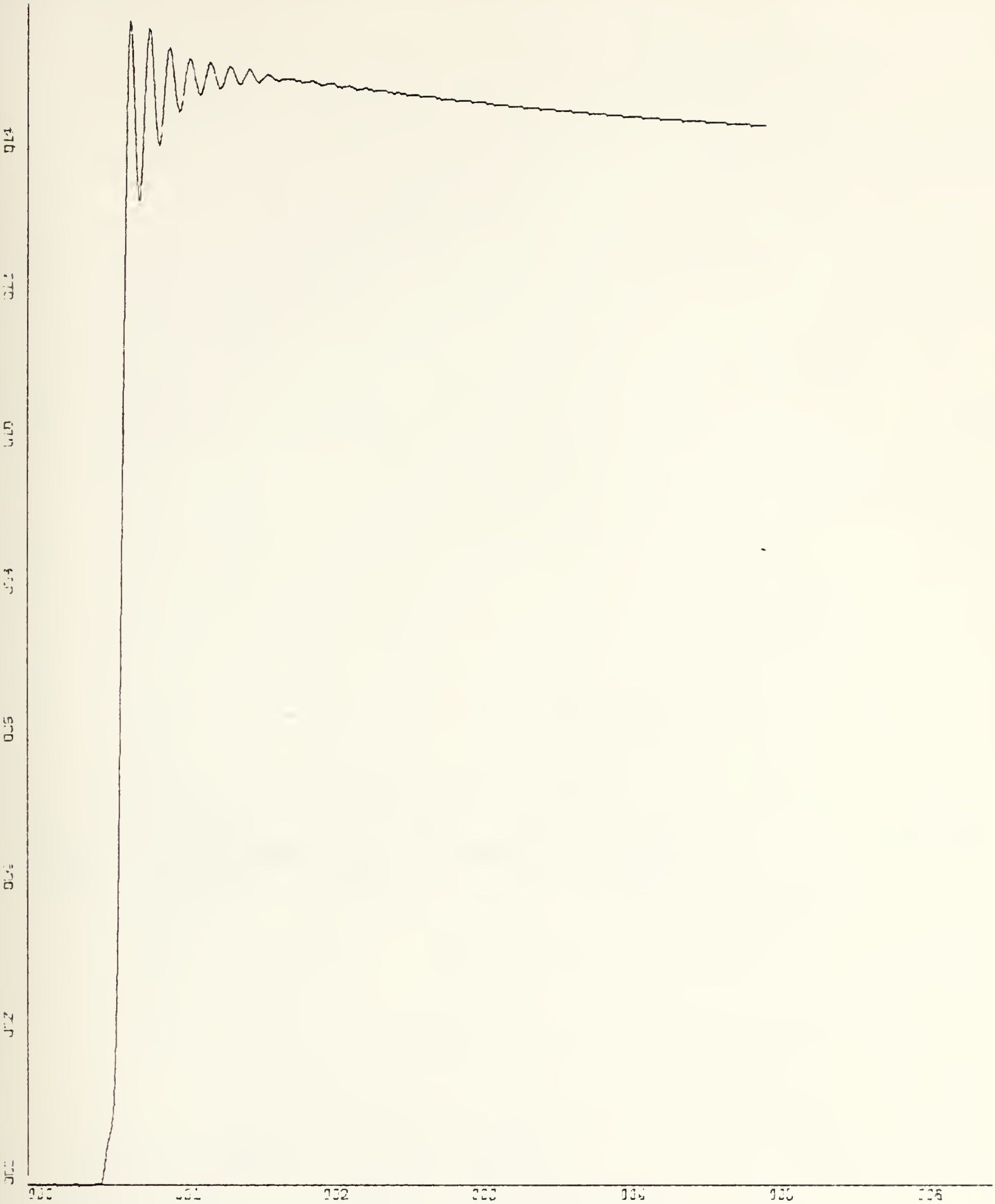
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
AGRT14 , TURN 20 KN.
PLOT IS ROLL RATE VERSUS TIME

PLOT 48

for applied parameters see first page of this appendix

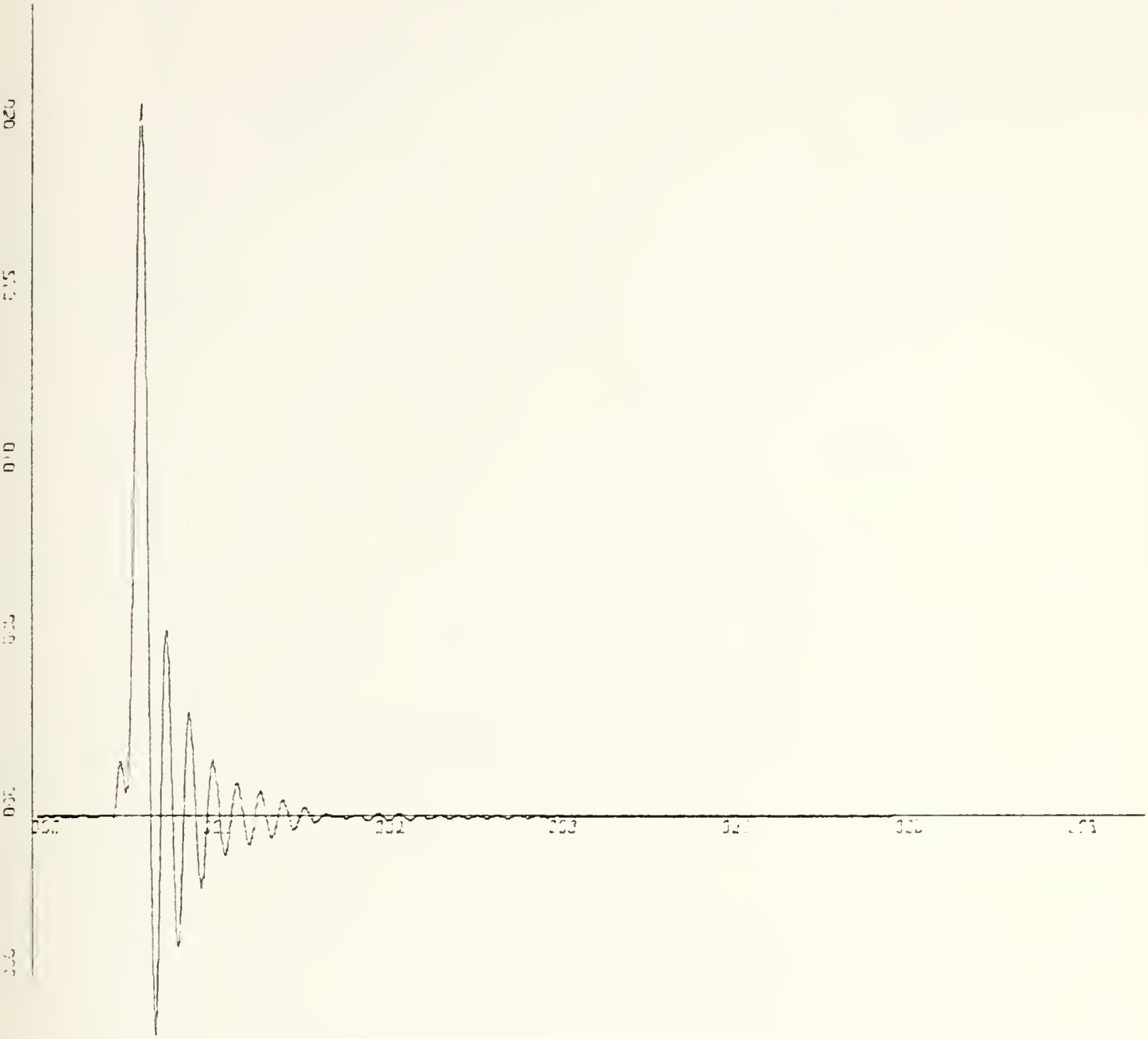


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 49

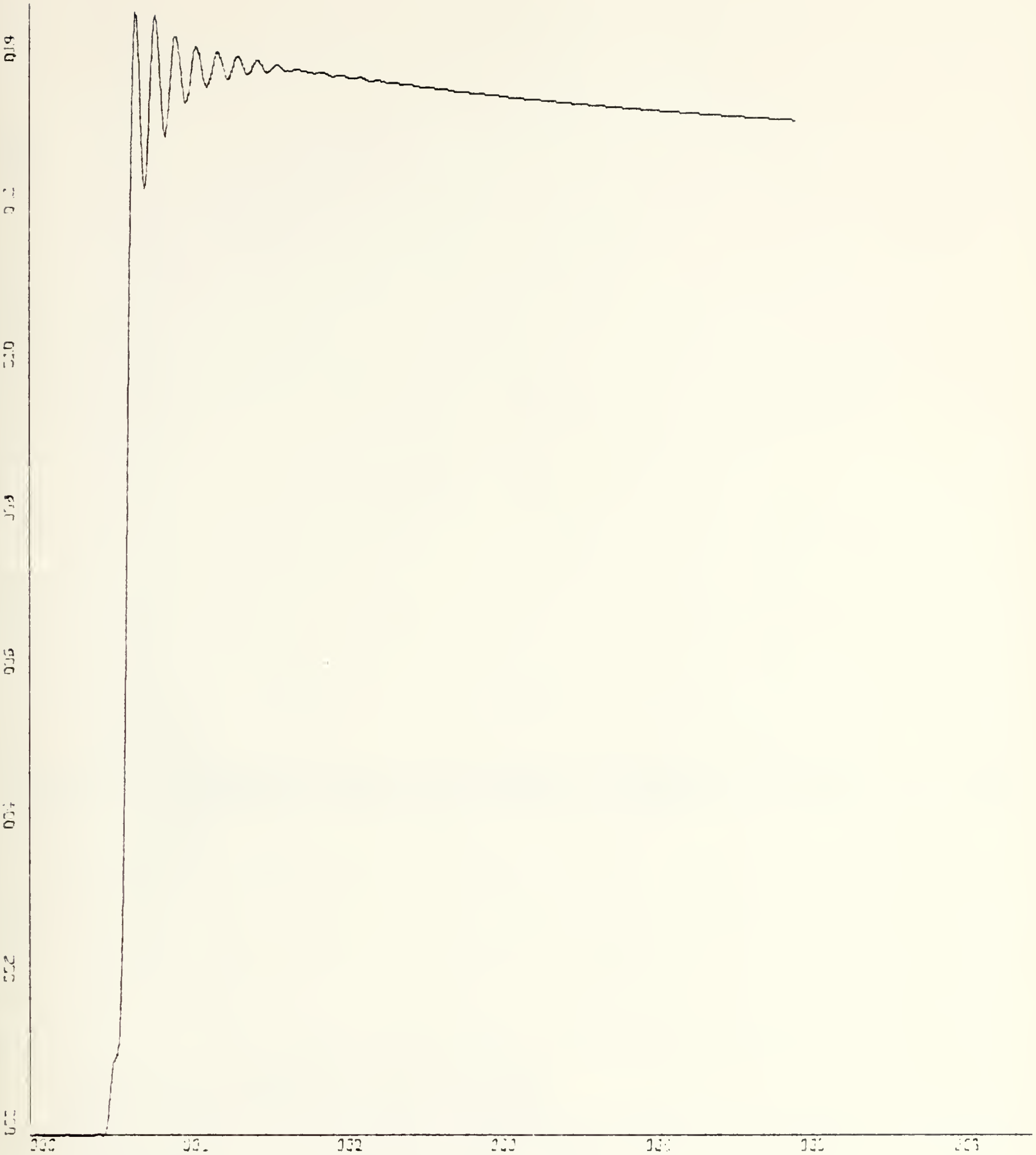
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RUN001 ; TURN 20 KN
PLOT IS ROLL RATE VERSUS TIME

PLOT 50

for applied parameters see first page of this appendix

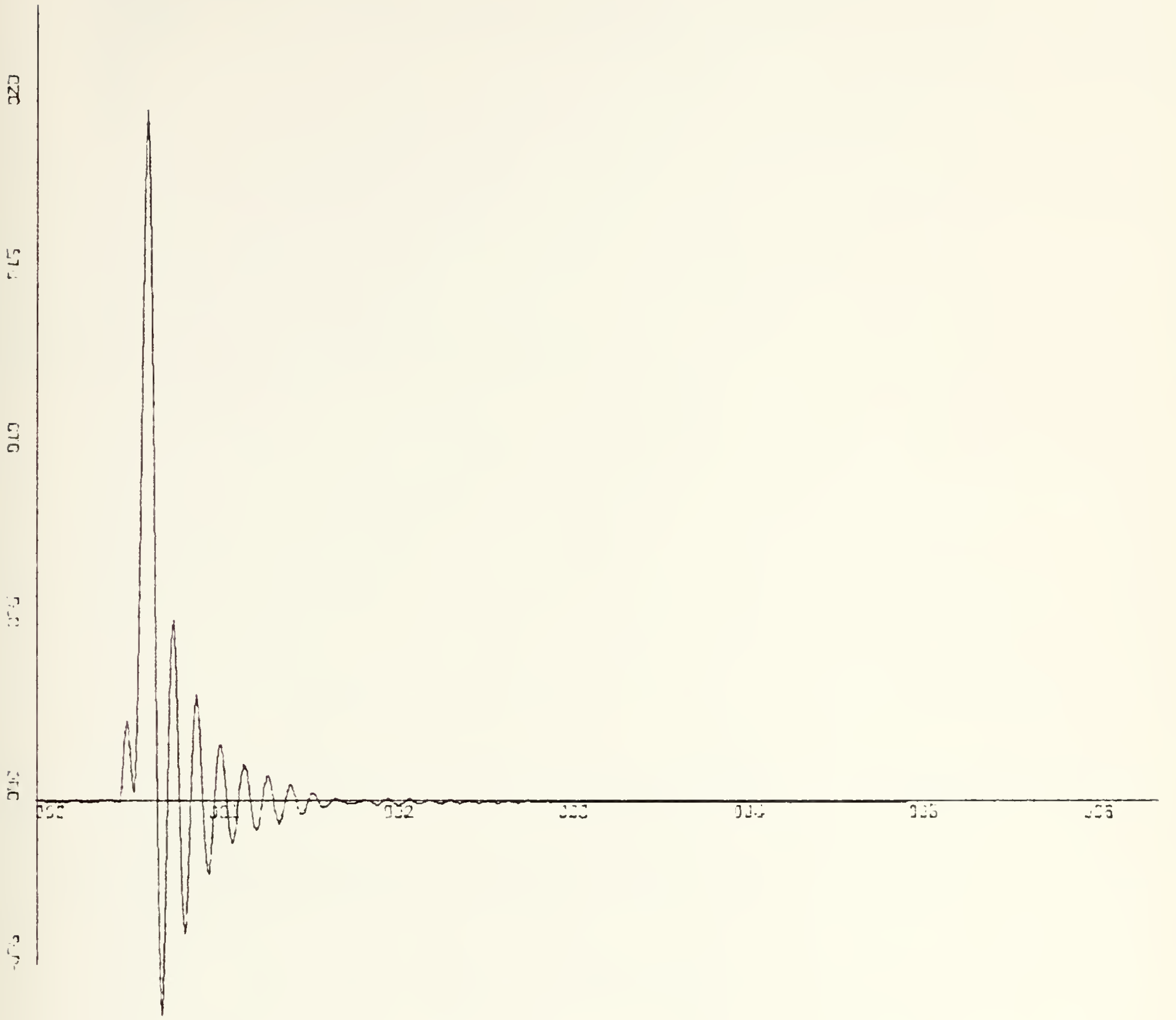


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 51

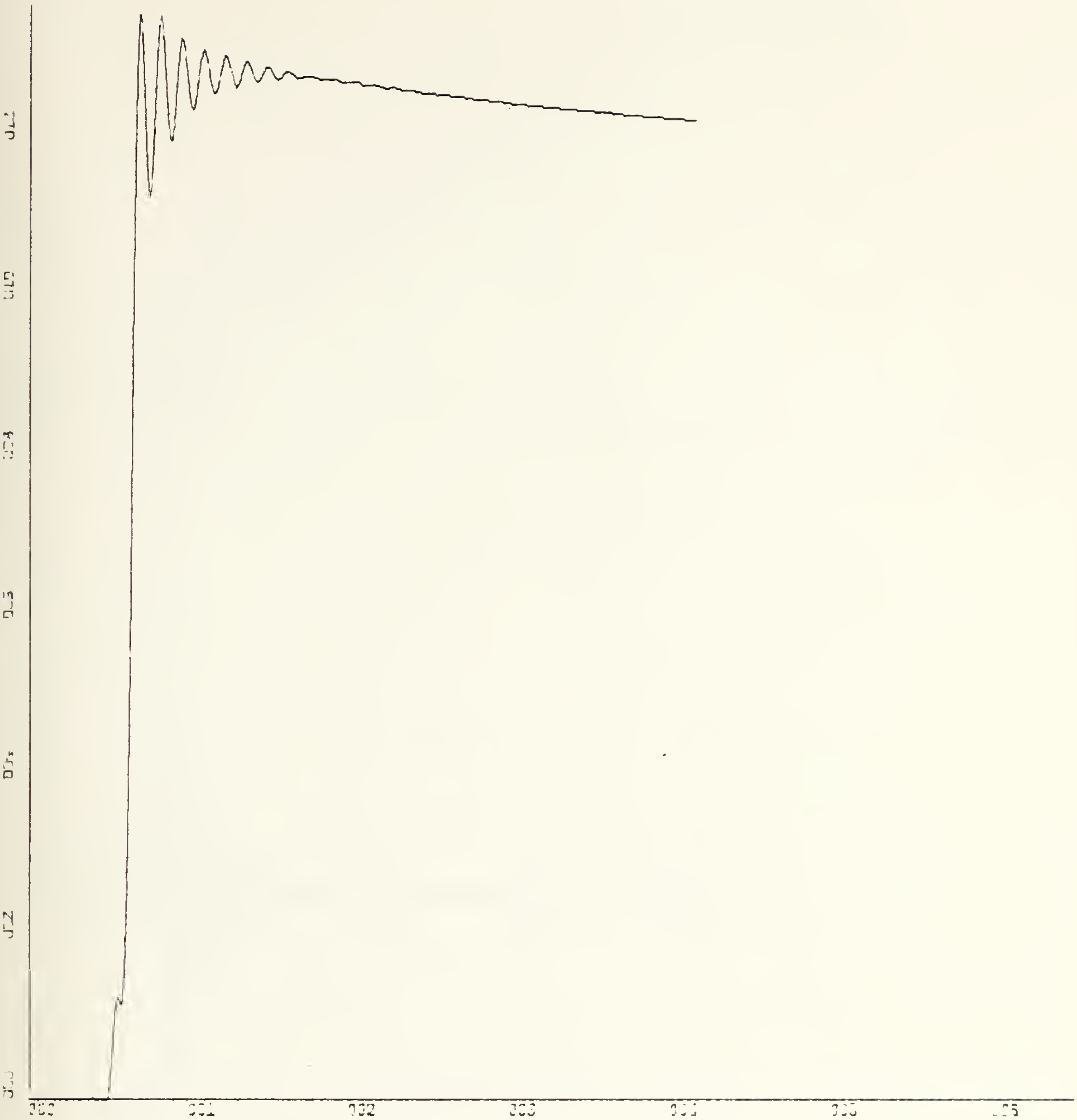
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RUNOD2 , TURN 20 KN
PLØT IS RØLL RATE VERSUS TIME

PLOT 52

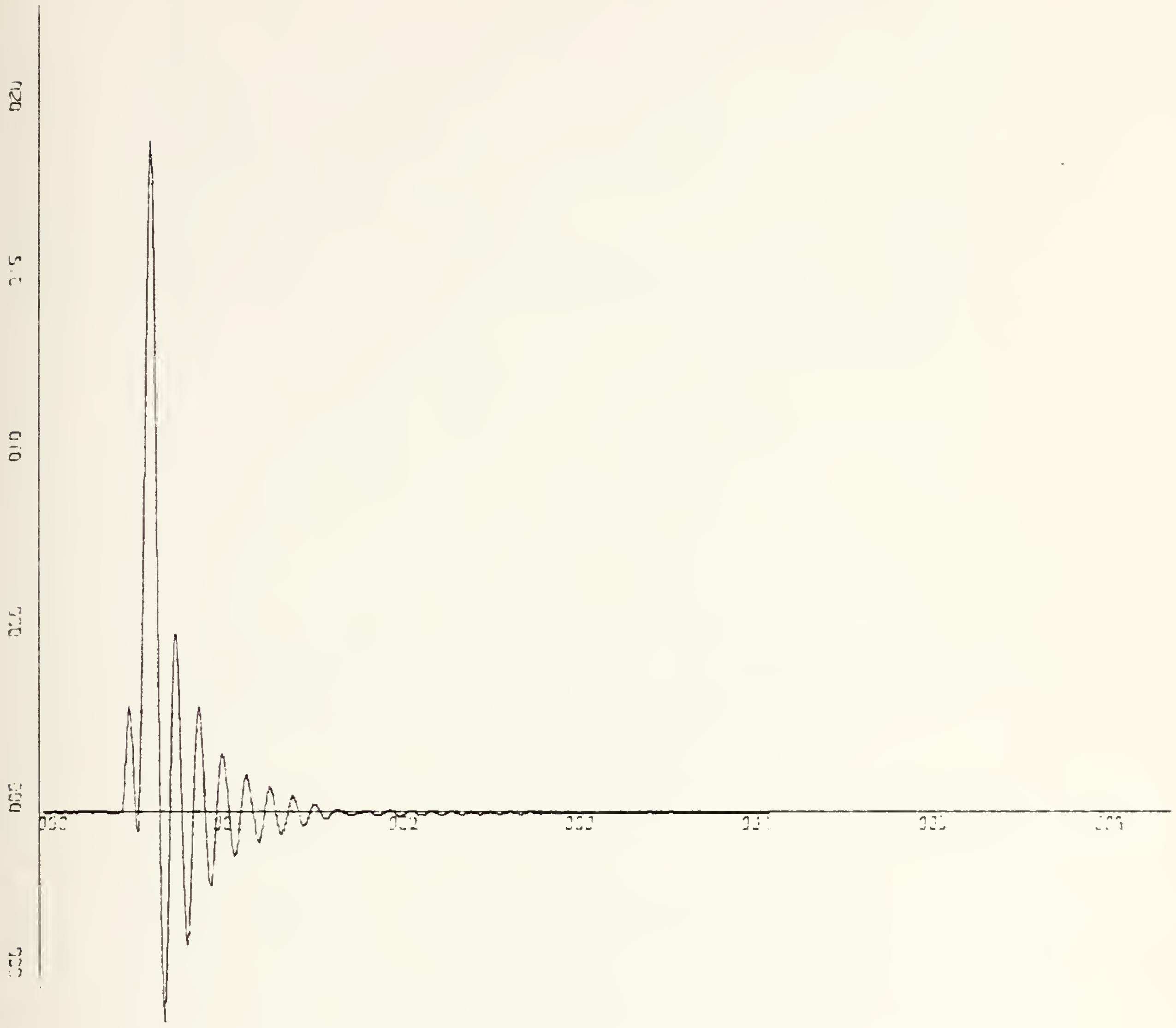
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
RUN0D3 , TURN 20 KN
PLØT IS ROLL ANGLE VERSUS TIME

PLOT 53

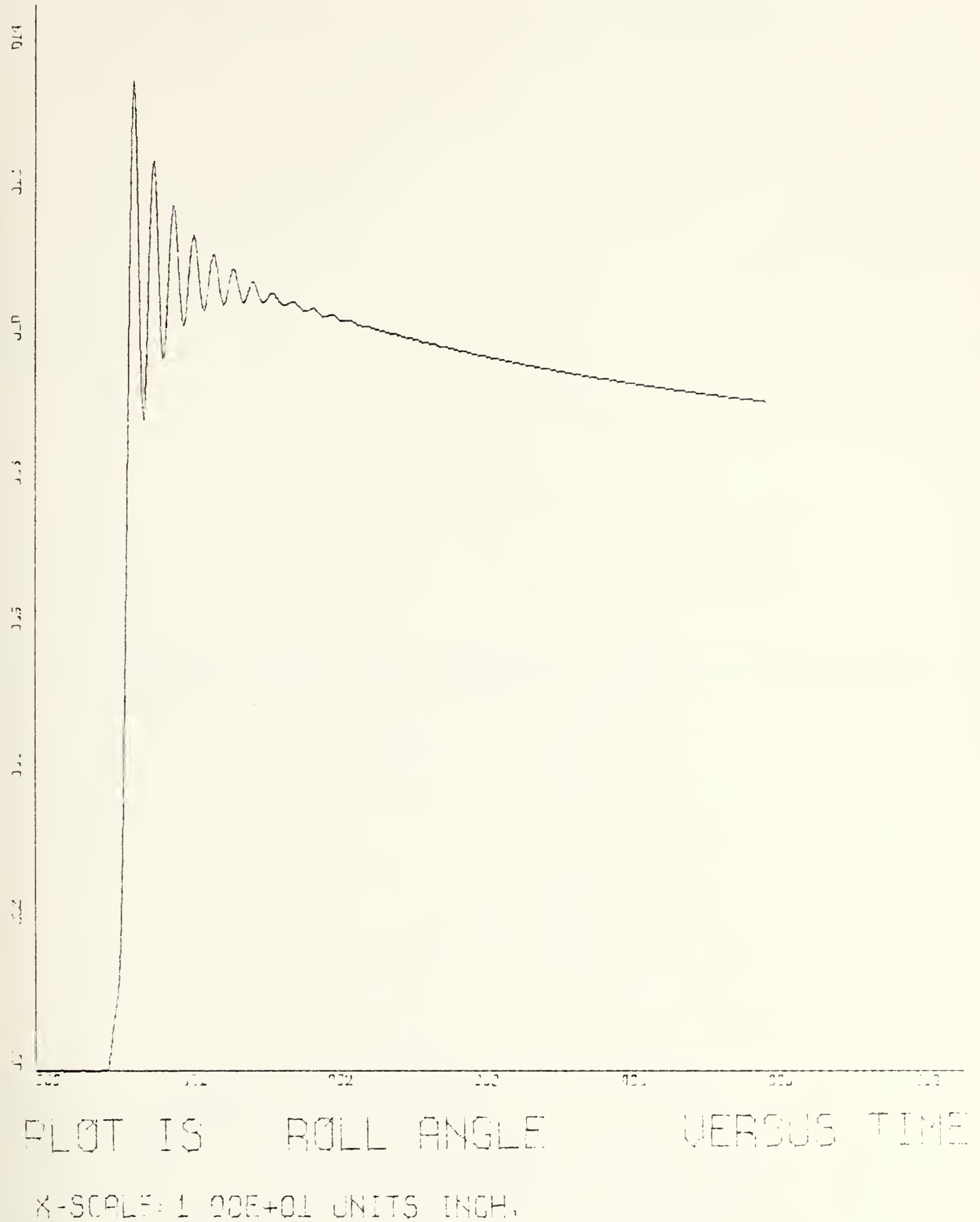
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
RUN003 . TURN 20 KN
PLOT IS ROLL RATE VERSUS TIME

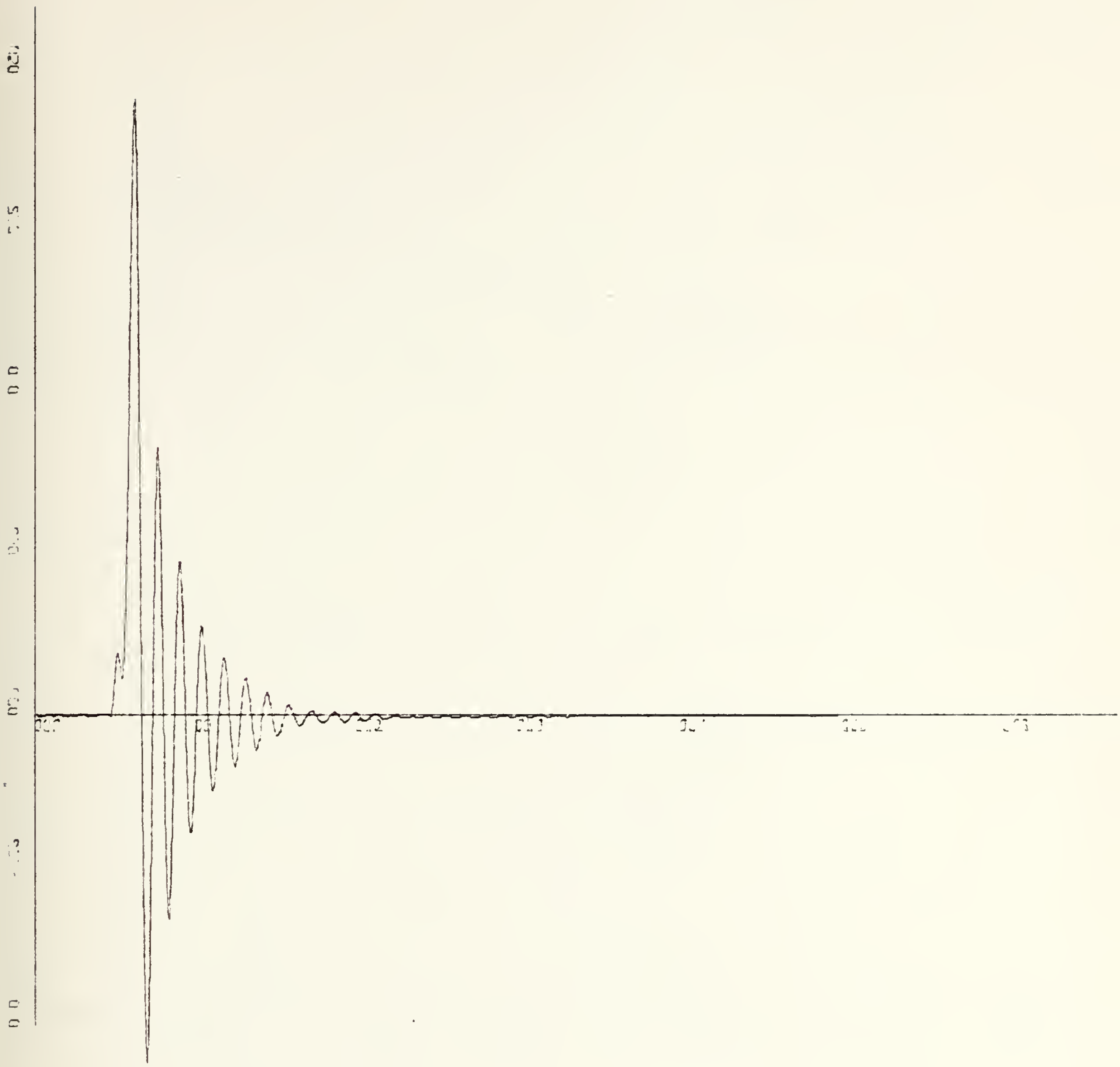
PLOT 54

for applied parameters see first page of this appendix



PLOT 55

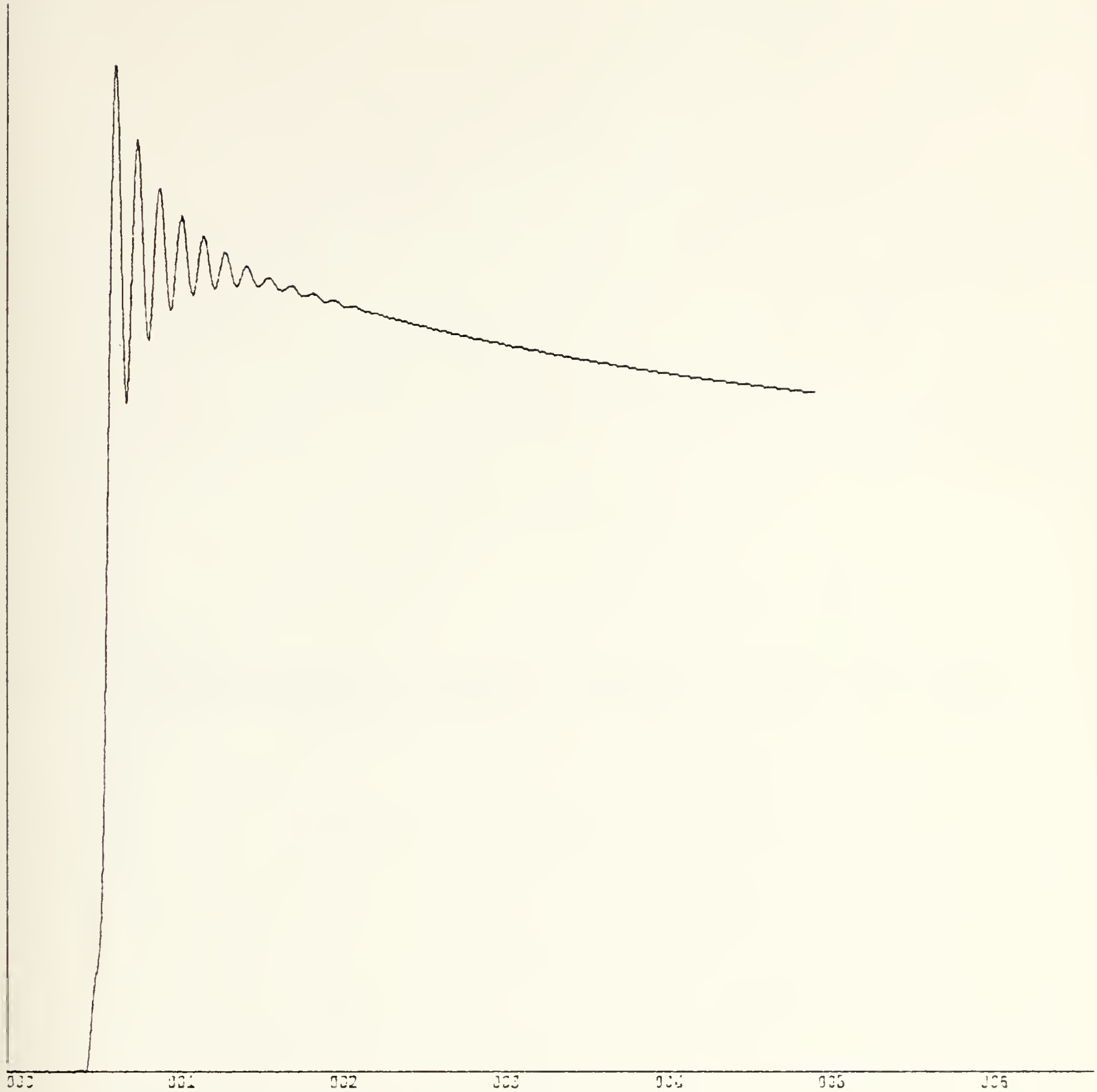
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROF1 , TURN 20 KN , RUD=10 , NO RC
PLOT IS ROLL RATE VERSUS TIME

PLOT 56

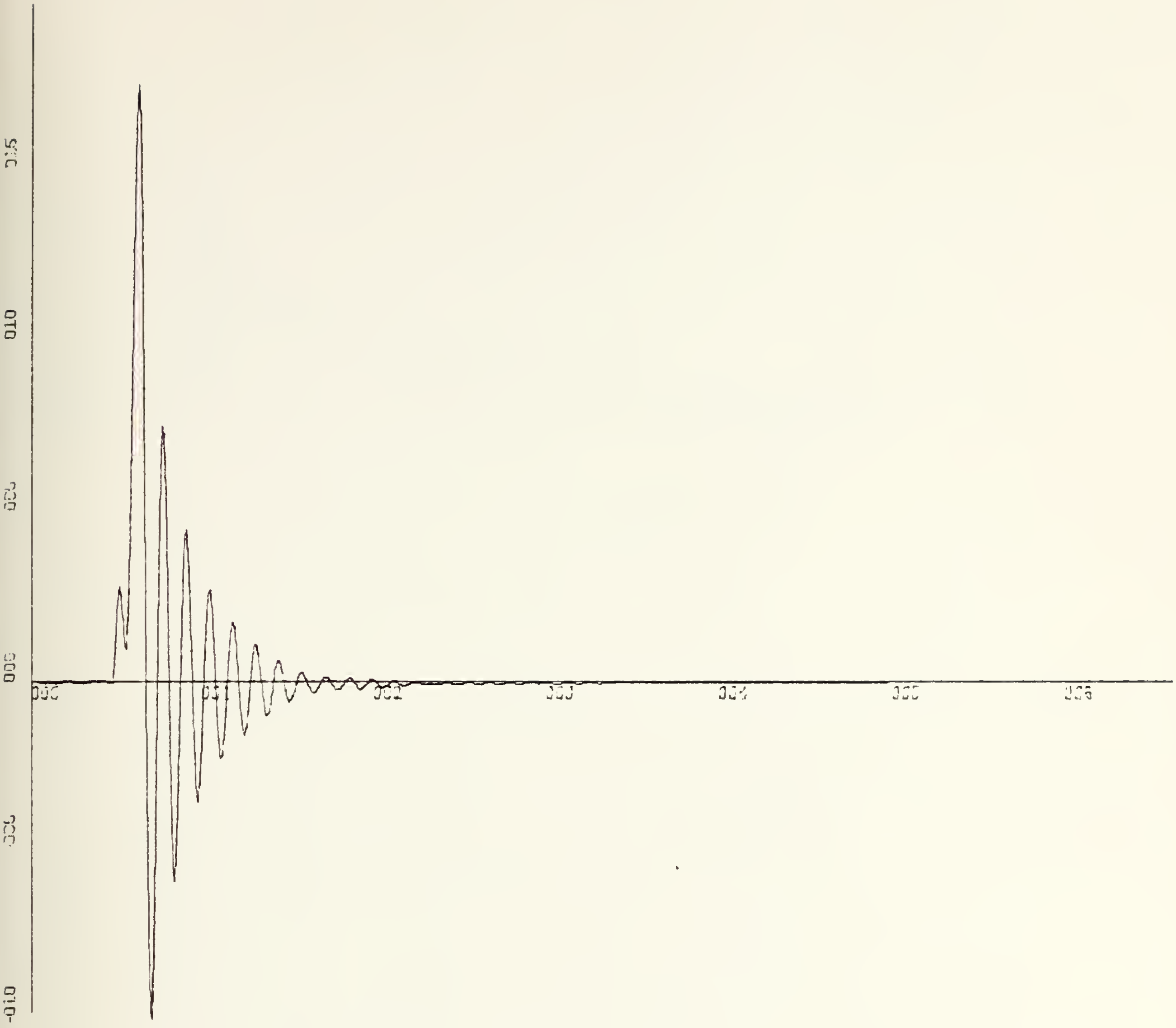
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
RGROF4 , TURN 20 KN , RUD=10 , NØ RD
PLØT IS RØLL ANGLE VERSUS TIME

PLOT 57

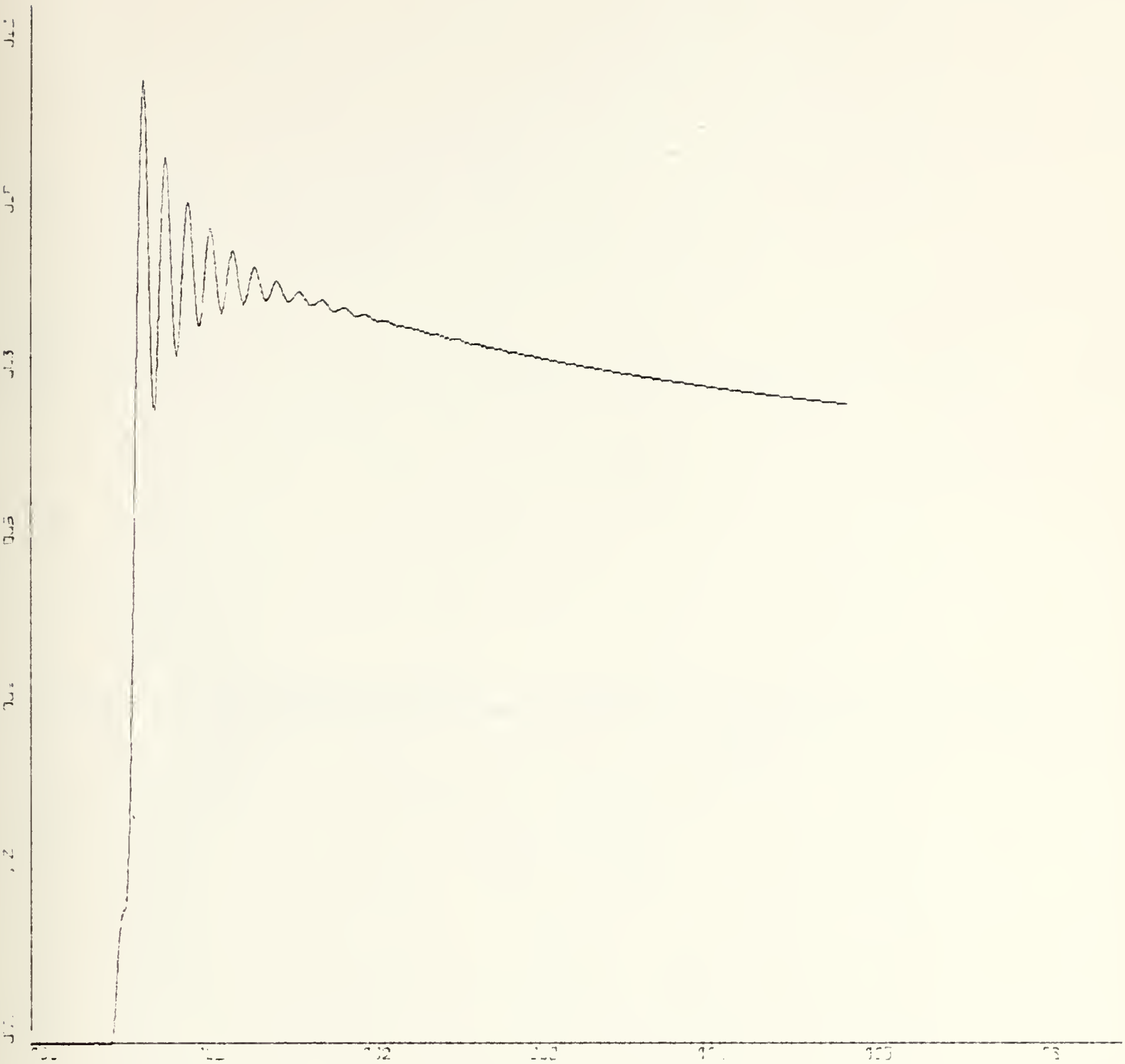
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROF4 , TURN 20 KN , RUD=10 , NO RD
PLOT IS ROLL RATE VERSUS TIME

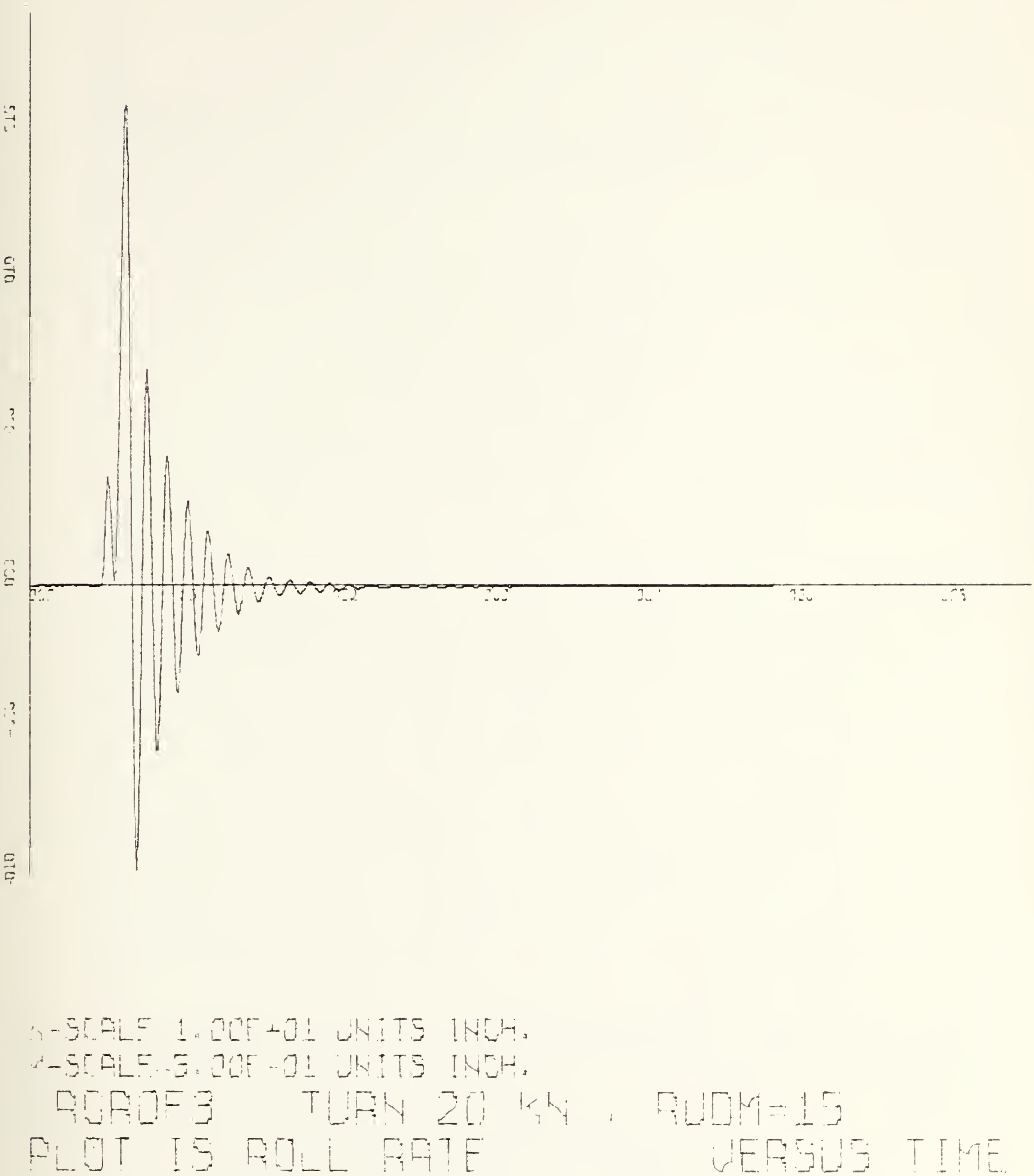
PLOT 58

for applied parameters see first page of this appendix



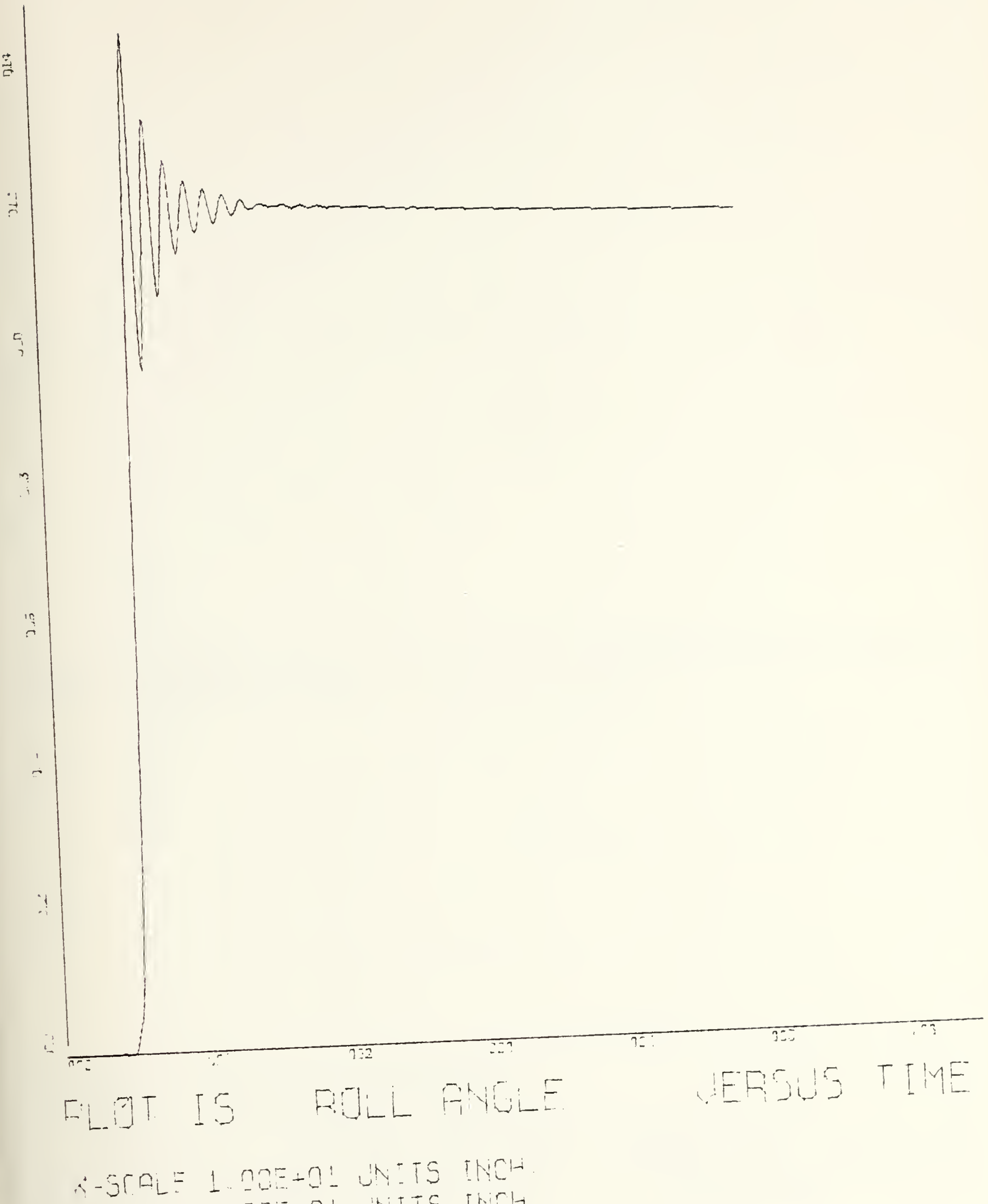
X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 2.00E-01 UNITS INCH.
RCROF3 . TURN 20 KN . RUDM=15
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 59
for applied parameters see first page of this appendix



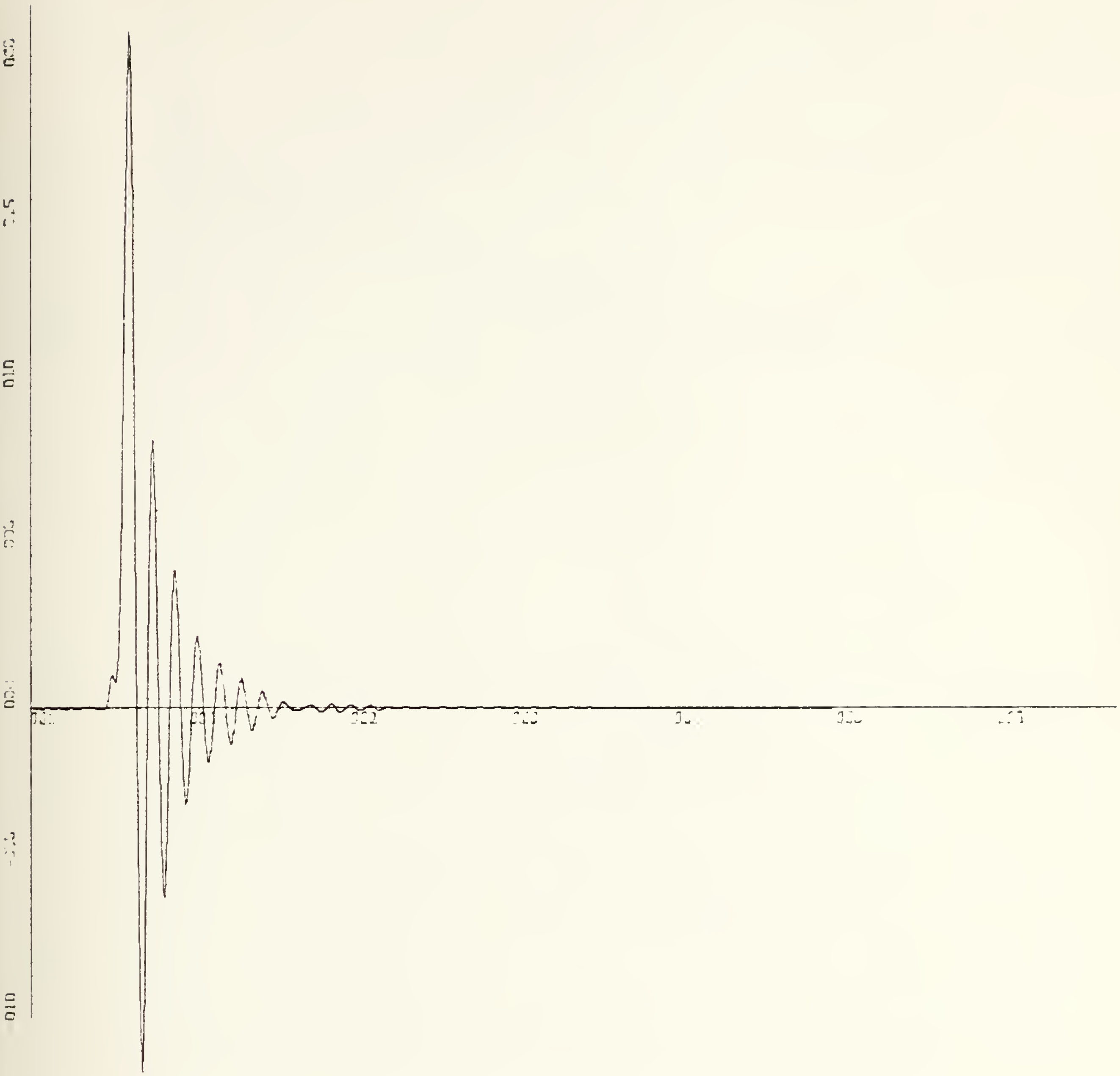
PLOT 60

for applied parameters see first page of this appendix



PLOT 61

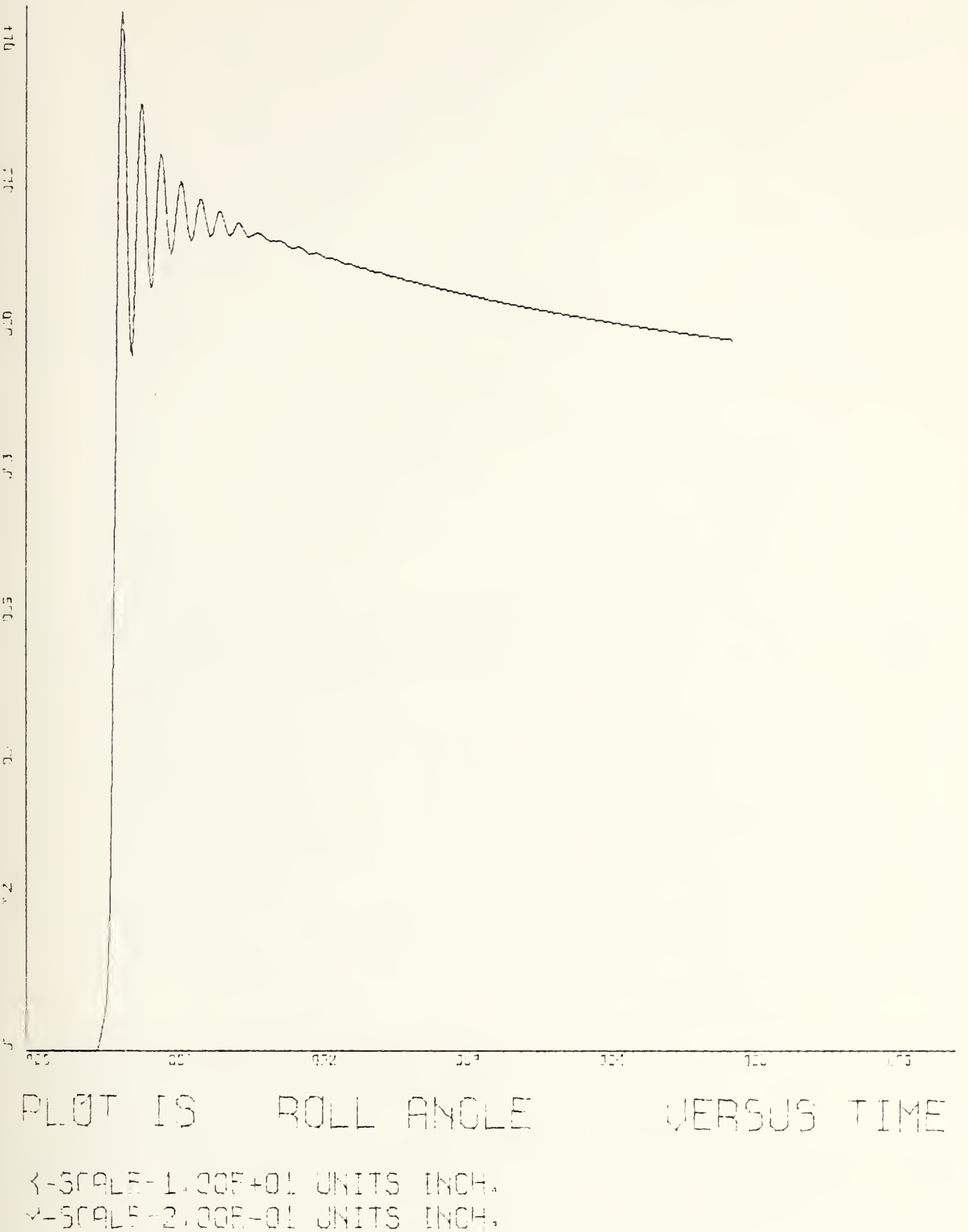
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROE6 , TURN 20 KN , RUD=15 , NO RD
PLOT IS ROLL RATE VERSUS TIME

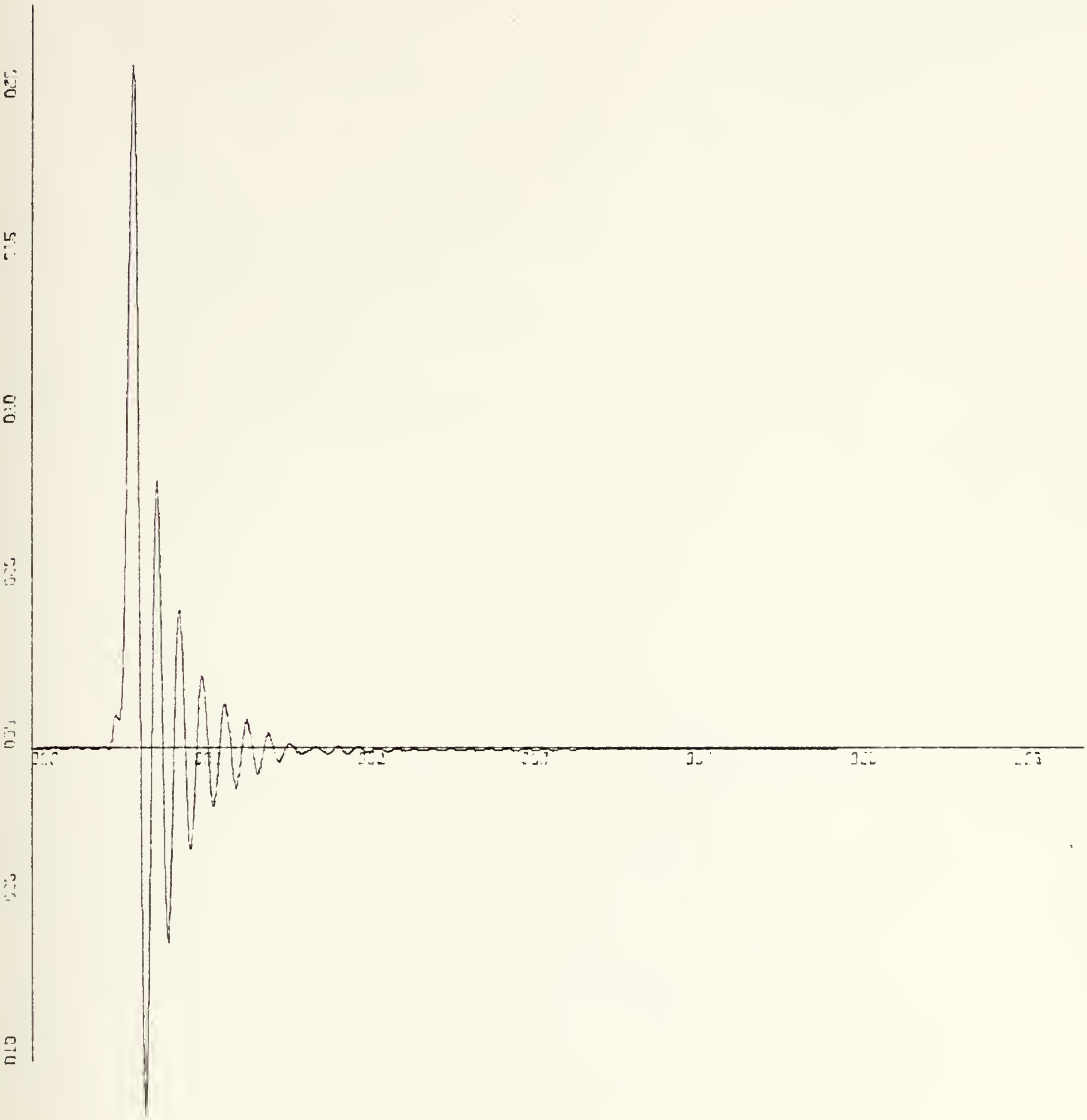
PLOT 62

for applied parameters see first page of this appendix



PLOT 63

for applied parameters see first page of this appendix



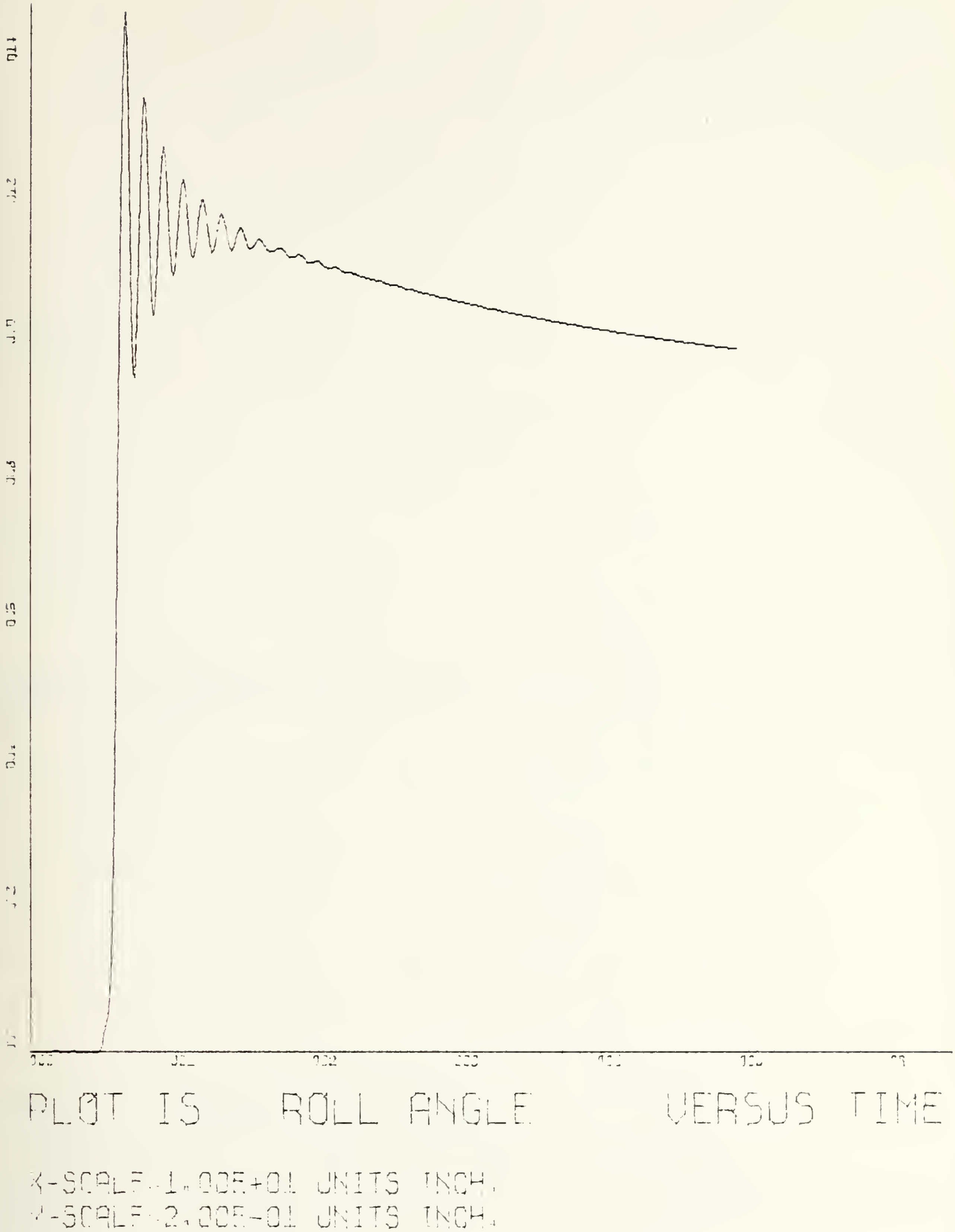
X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.

RGROE9 . TURN 20 KN , RUDM=15

PLOT IS ROLL RATE VERSUS TIME

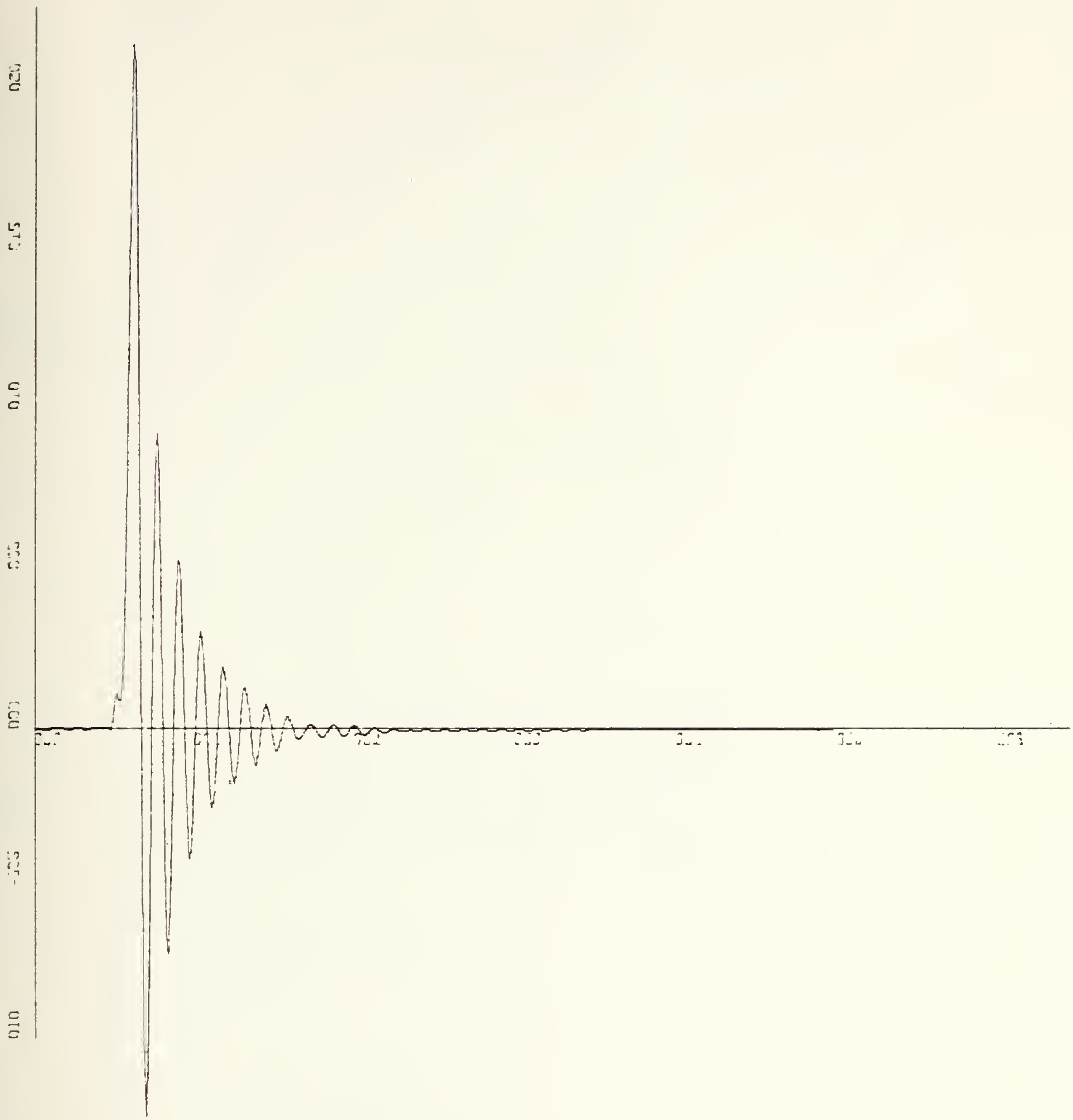
PLOT 64

for applied parameters see first page of this appendix



PLOT 65

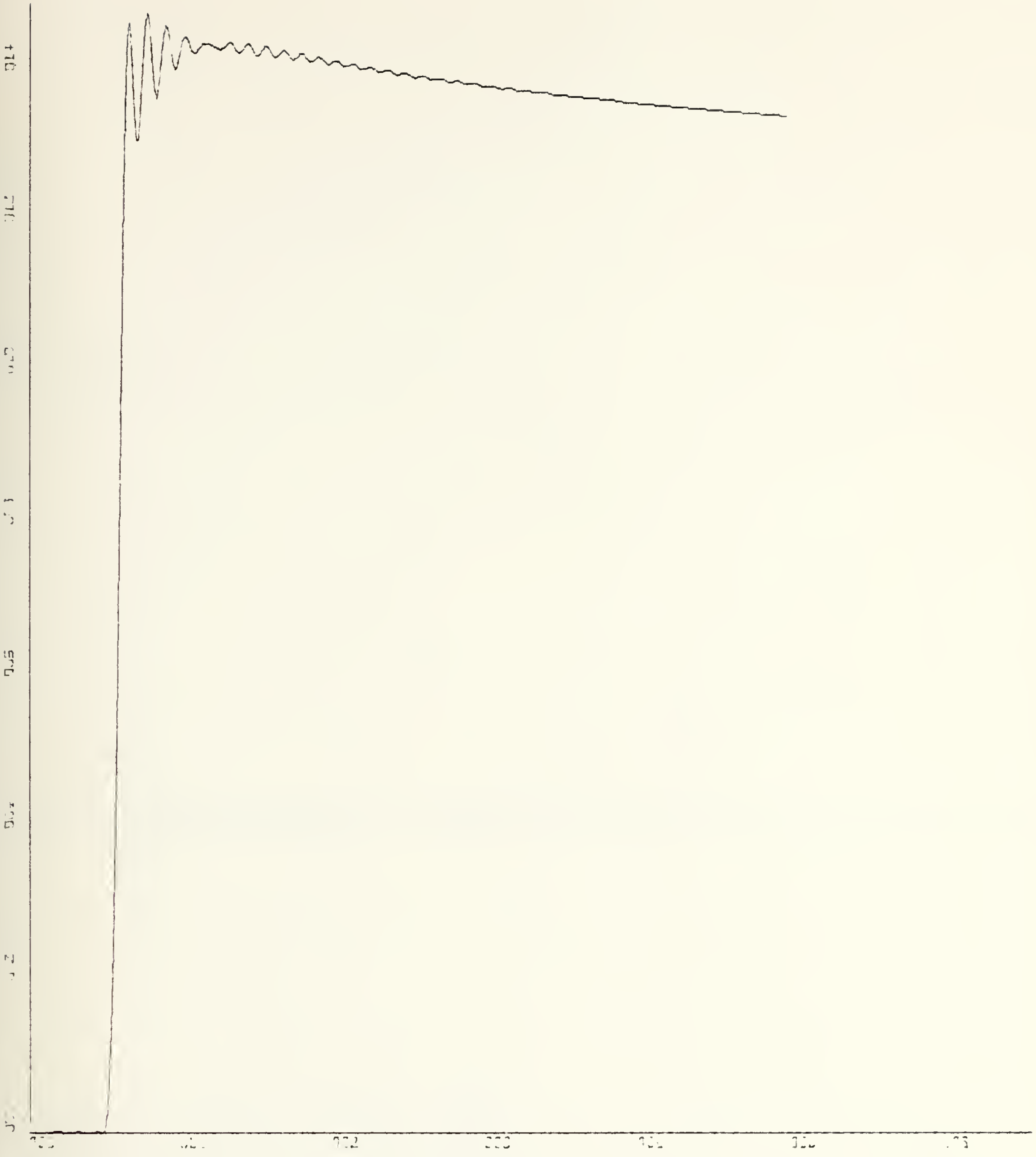
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRPE9 , TURN 20 KN , RUD=15
PLOT IS ROLL RATE VERSUS TIME

PLOT 66

for applied parameters see first page of this appendix

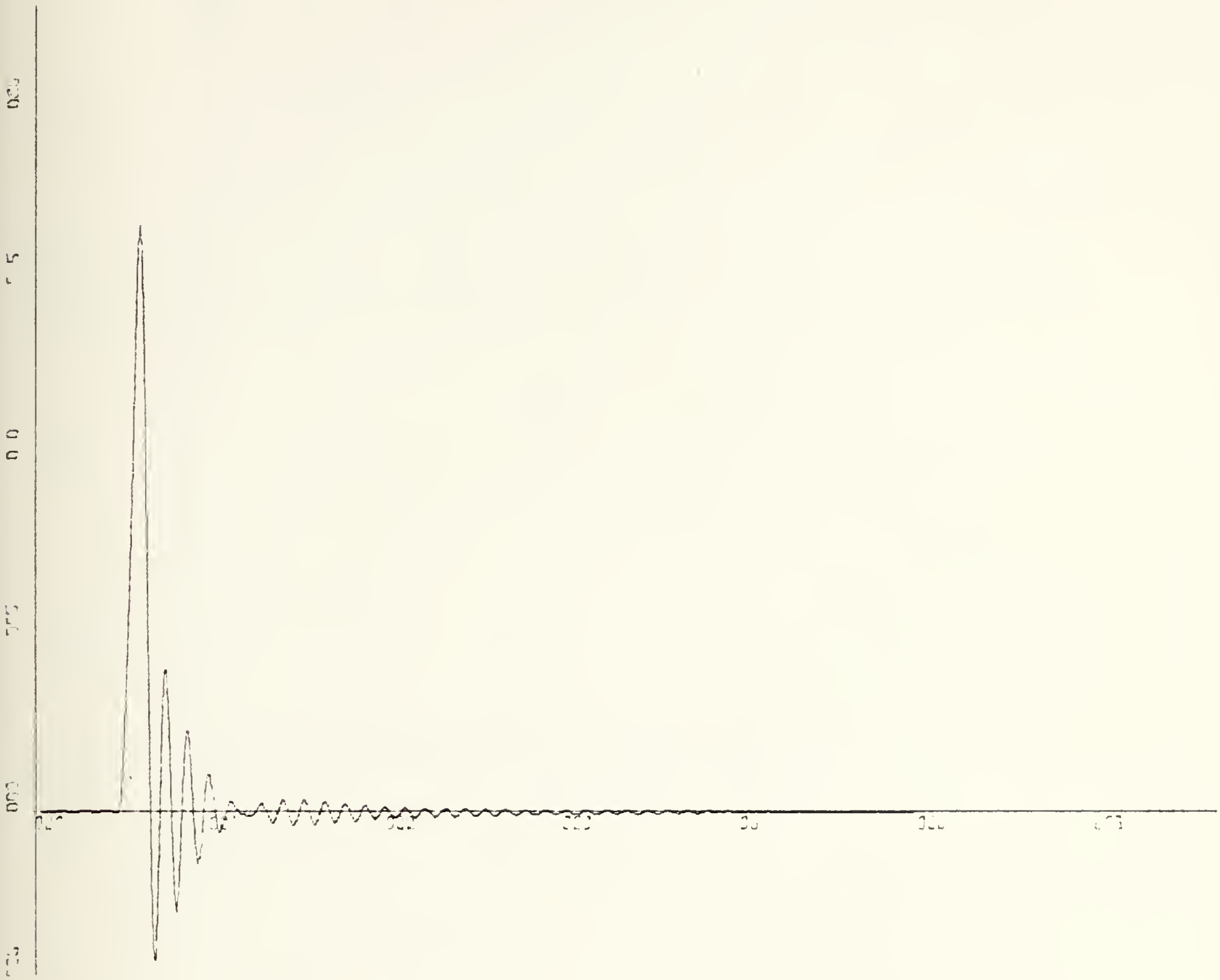


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 67

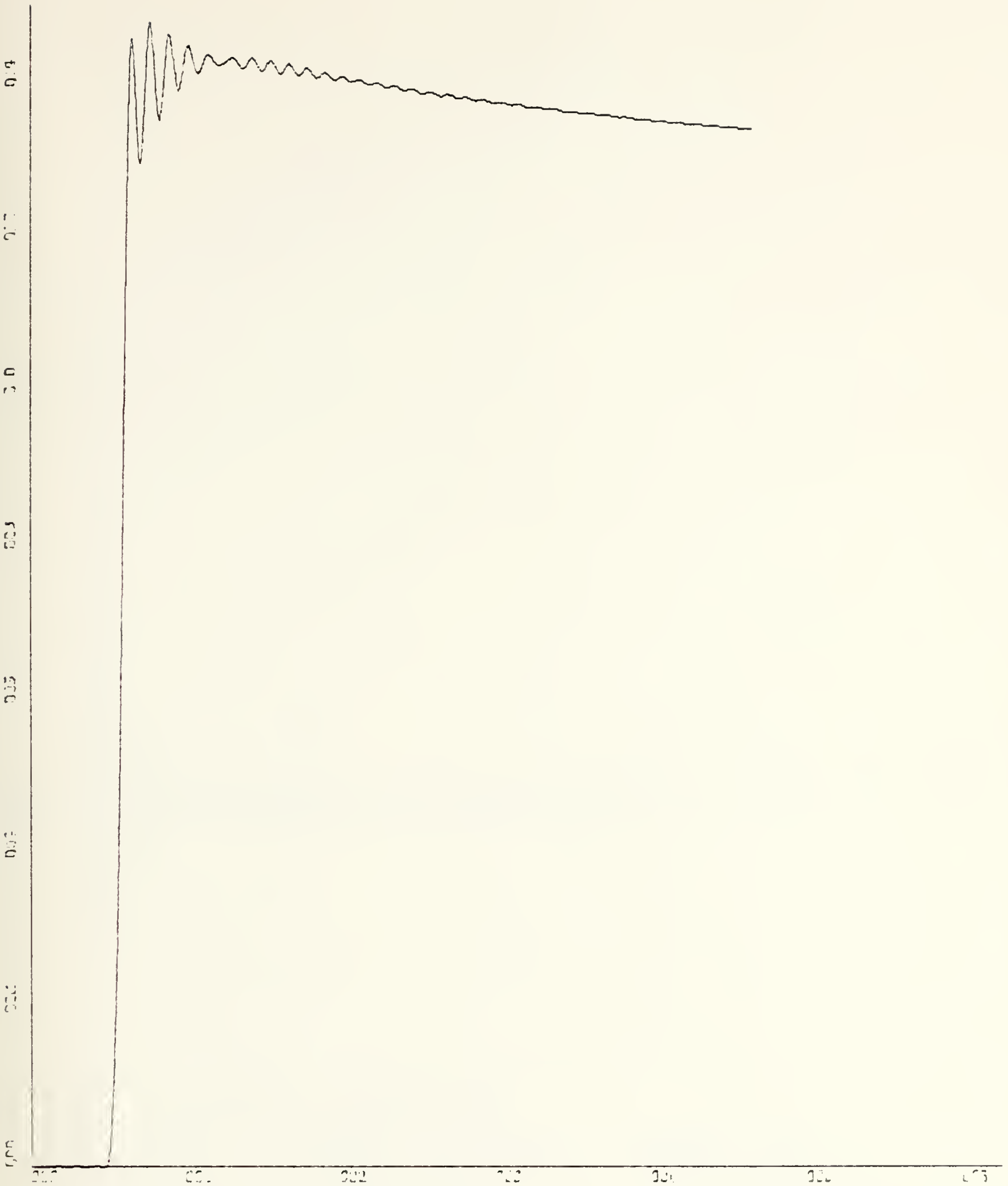
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 5.00E-01 UNITS INCH.
ACROFB . TURN 20 KN . RUD=15 . NO RD
PLOT IS ROLL RATE VERSUS TIME

PLOT 68

for applied parameters see first page of this appendix

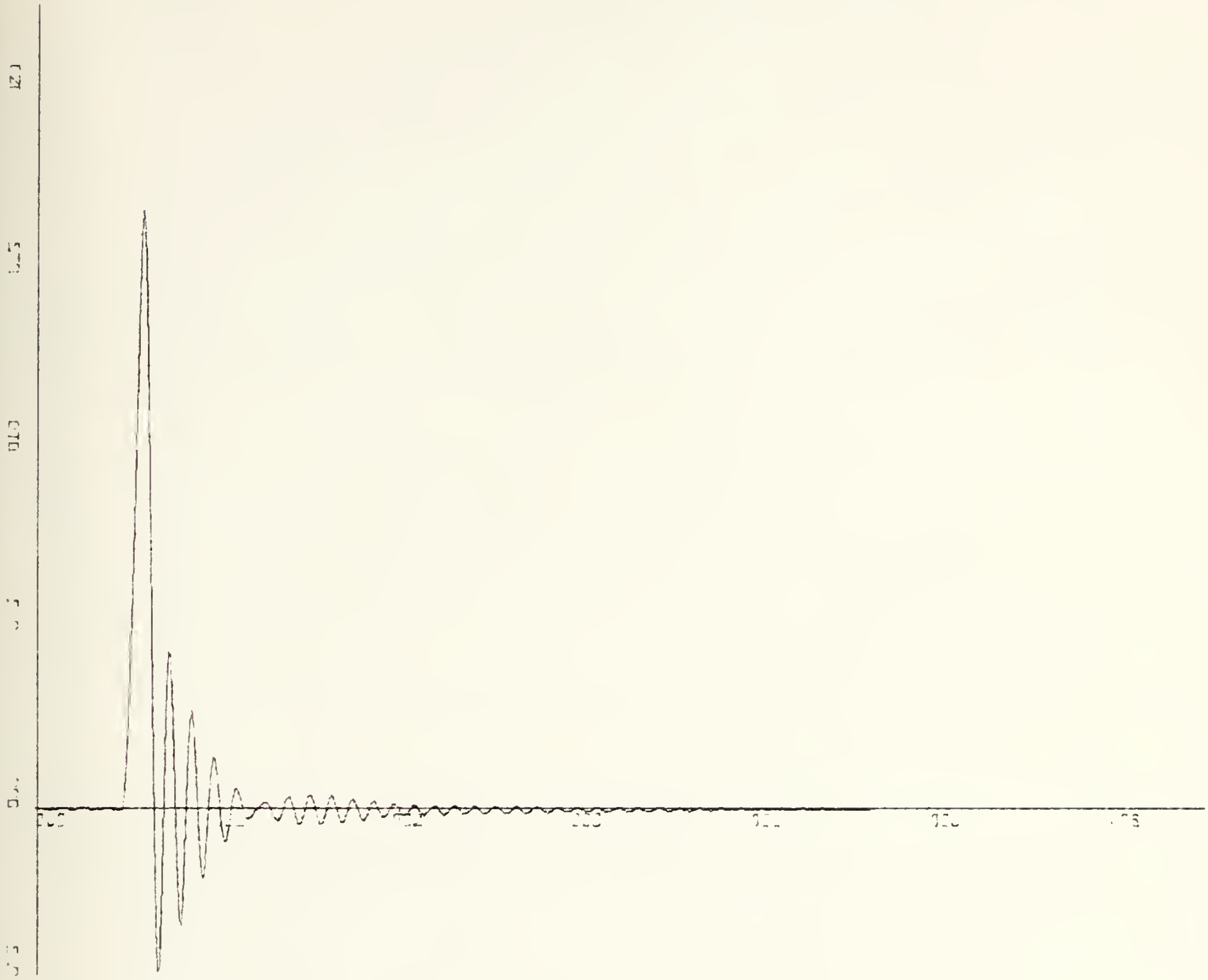


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 2.00E-01 UNITS INCH.

PLOT 69

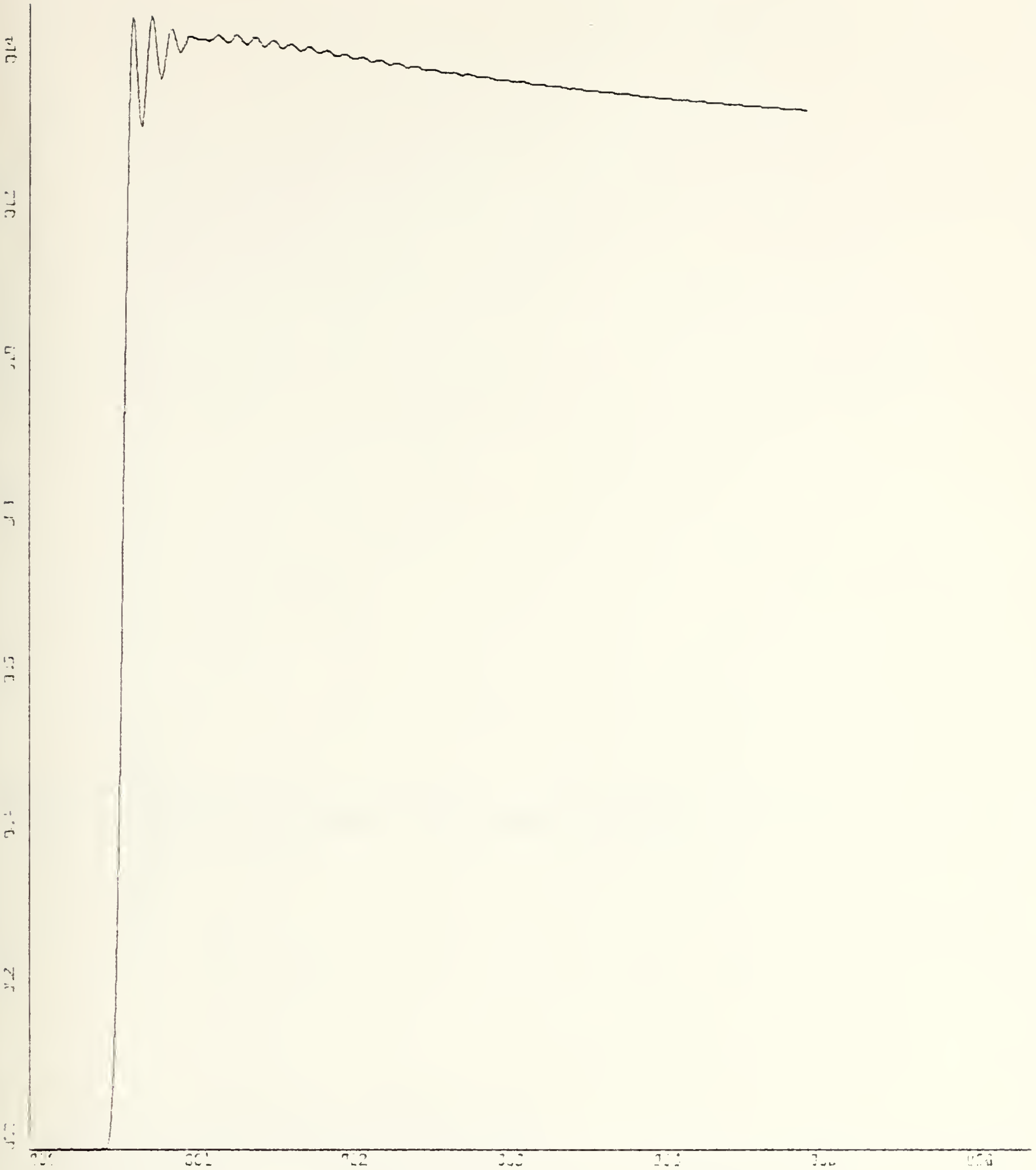
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGRPE8 , TURN 20 KN , RUD=15
PLØT IS RØLL RATE VERSUS TIME

PLOT 70

for applied parameters see first page of this appendix

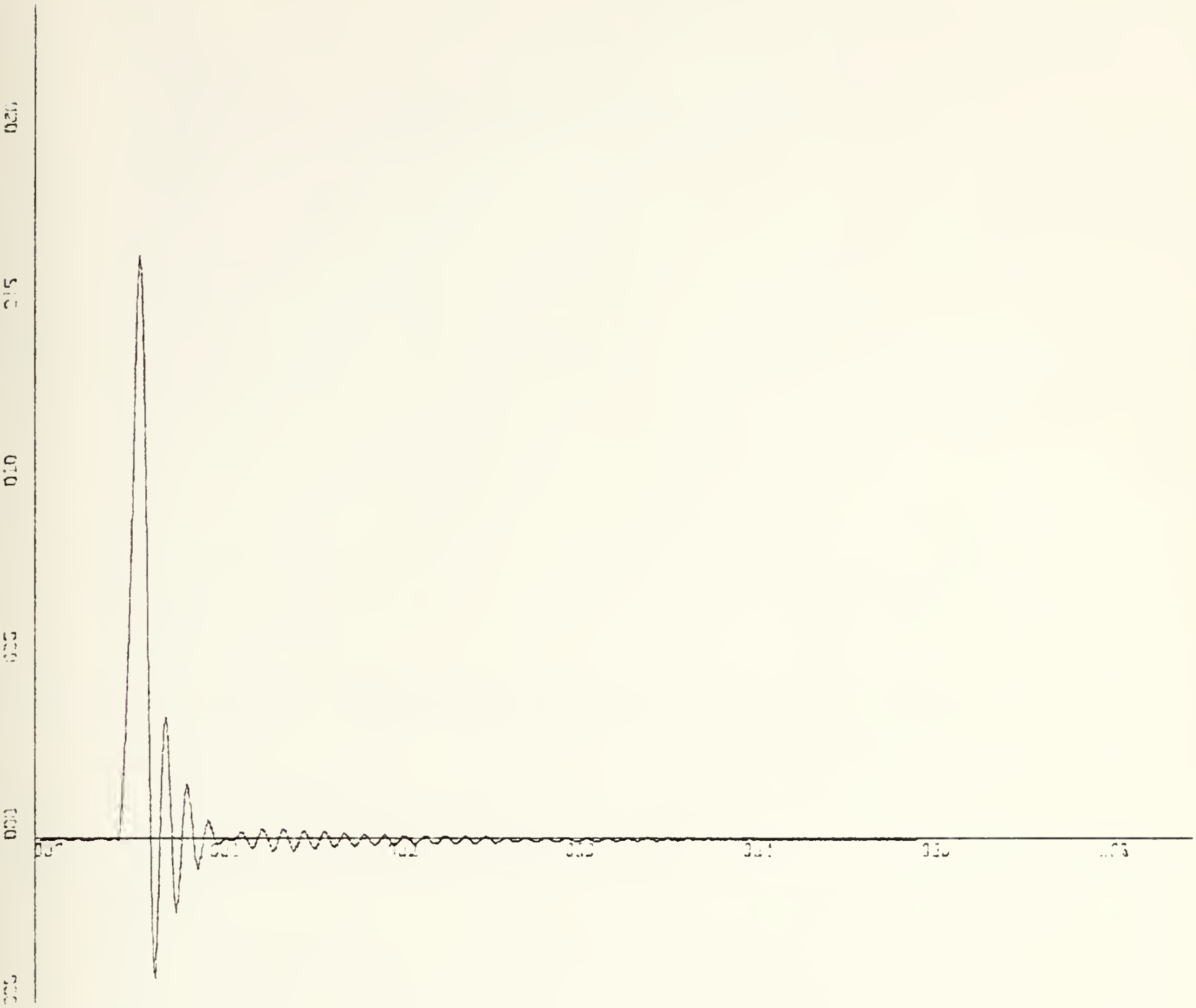


PLOT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

PLOT 71

for applied parameters see first page of this appendix



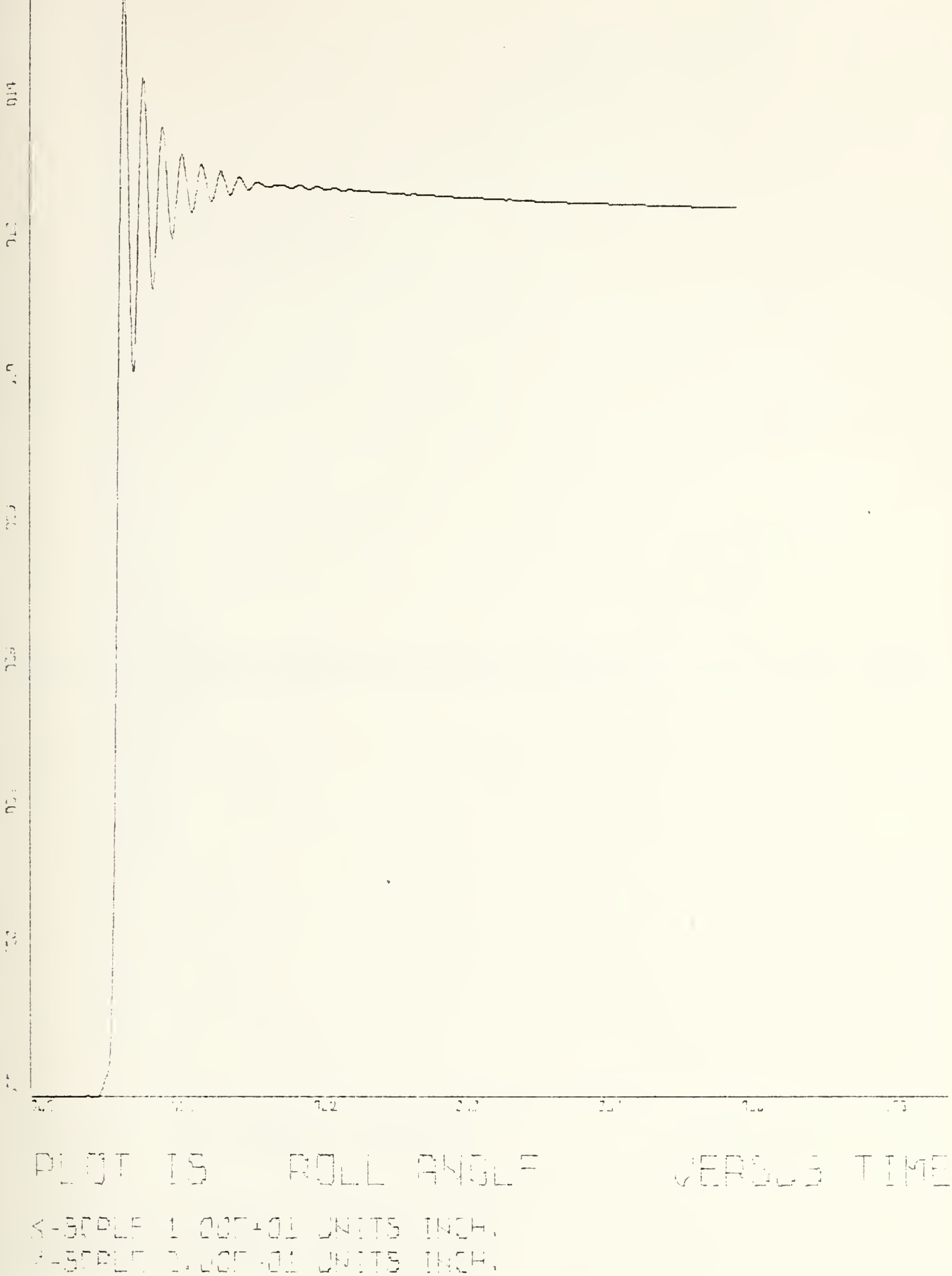
X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.

RGRP18 . TURN 20 KN . RUD=15

PLOT IS ROLL RATE VERSUS TIME

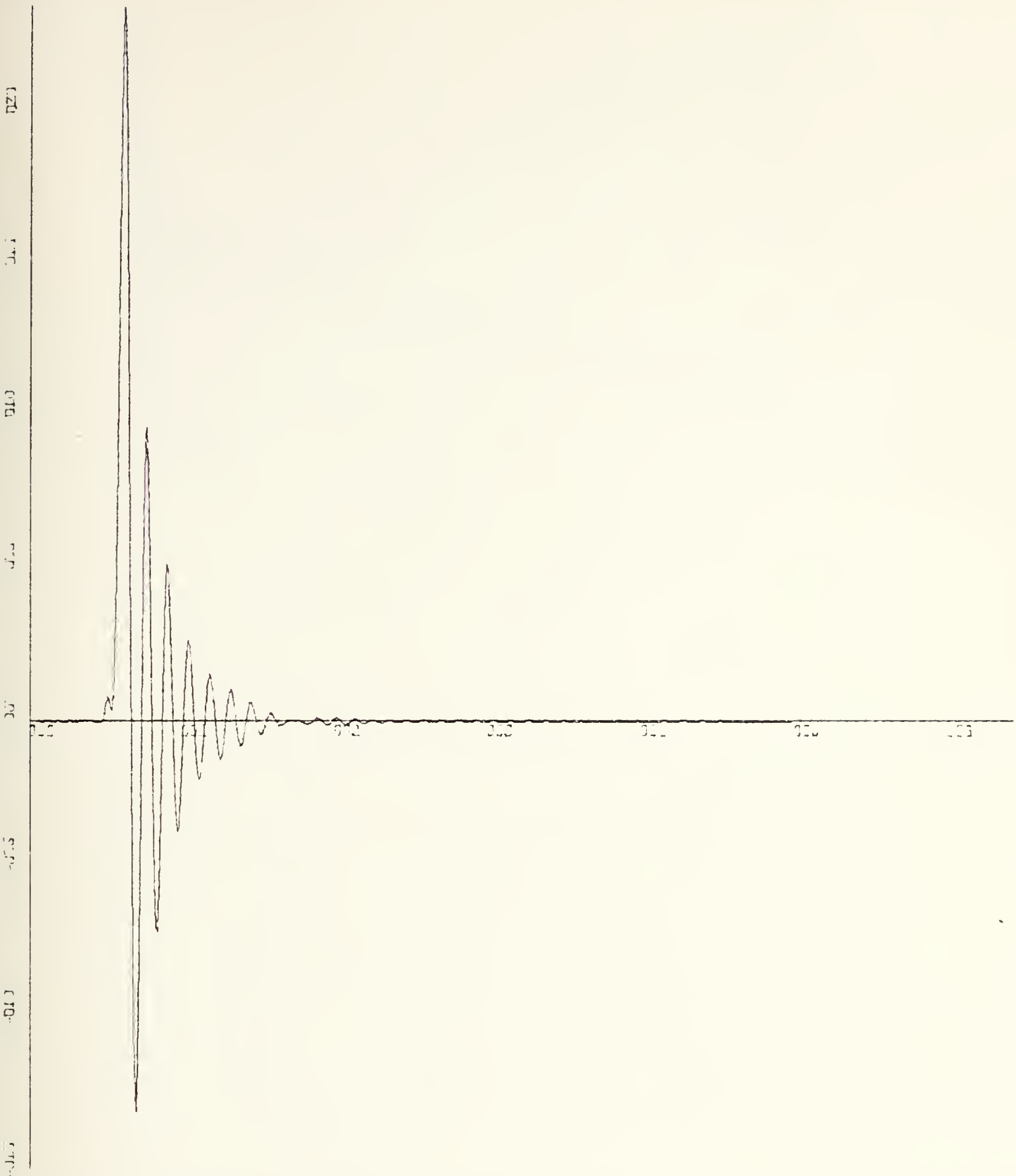
PLOT 72

for applied parameters see first page of this appendix



PLOT 73

for applied parameters see first page of this appendix

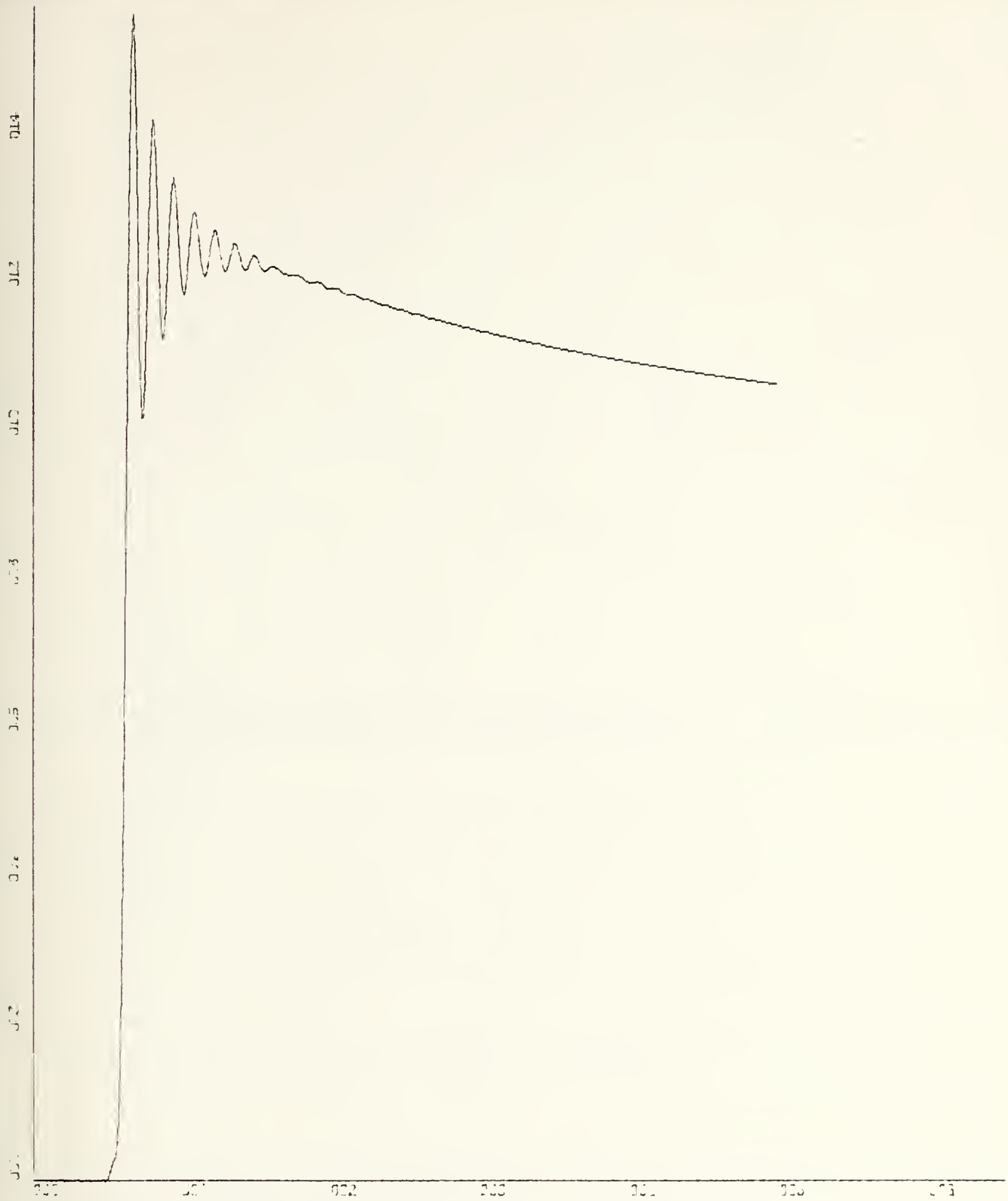


PLØT IS RØLL RATE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.

PLOT 74

for applied parameters see first page of this appendix

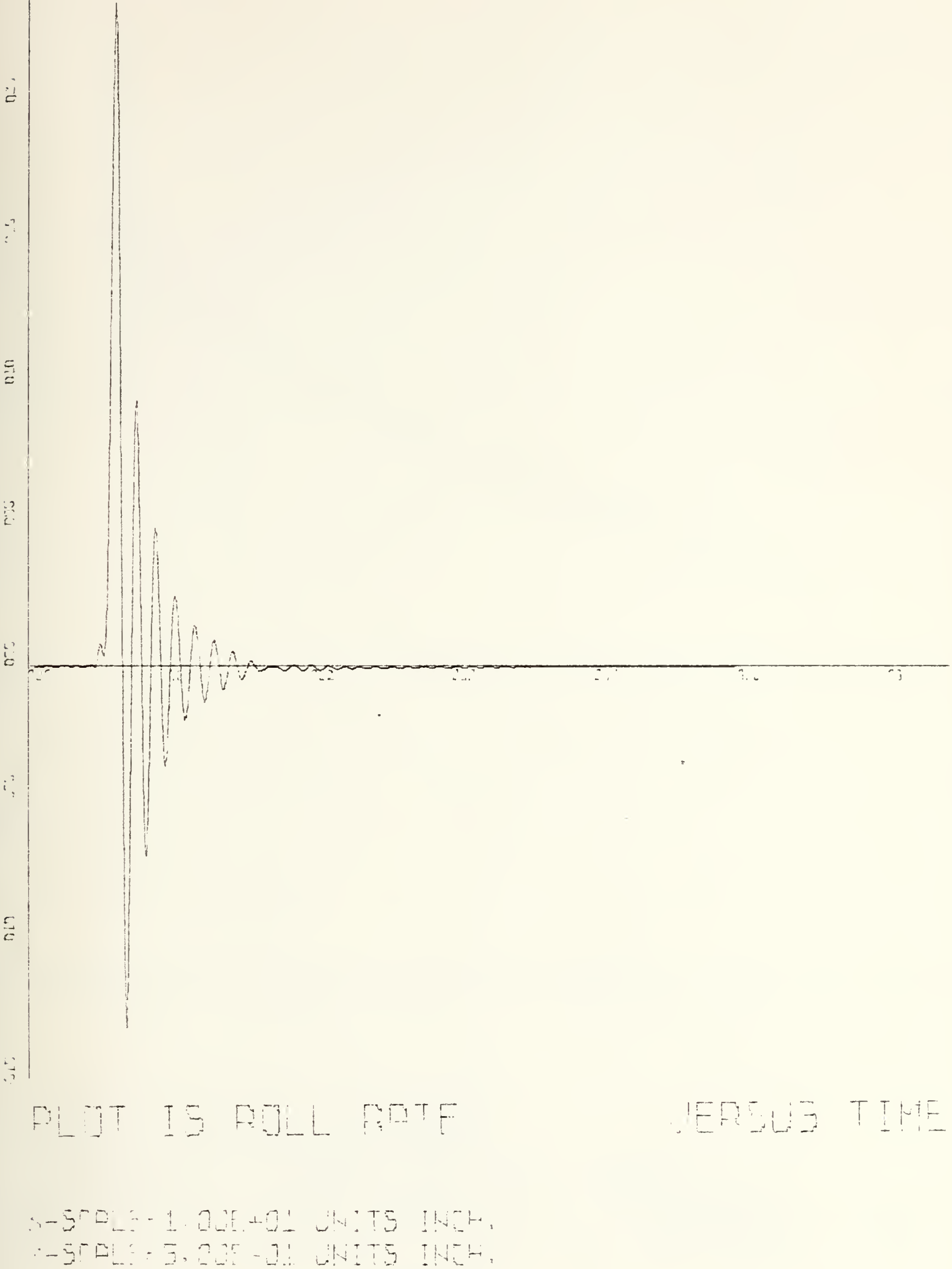


PLØT IS ROLL ANGLE VERSUS TIME

X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

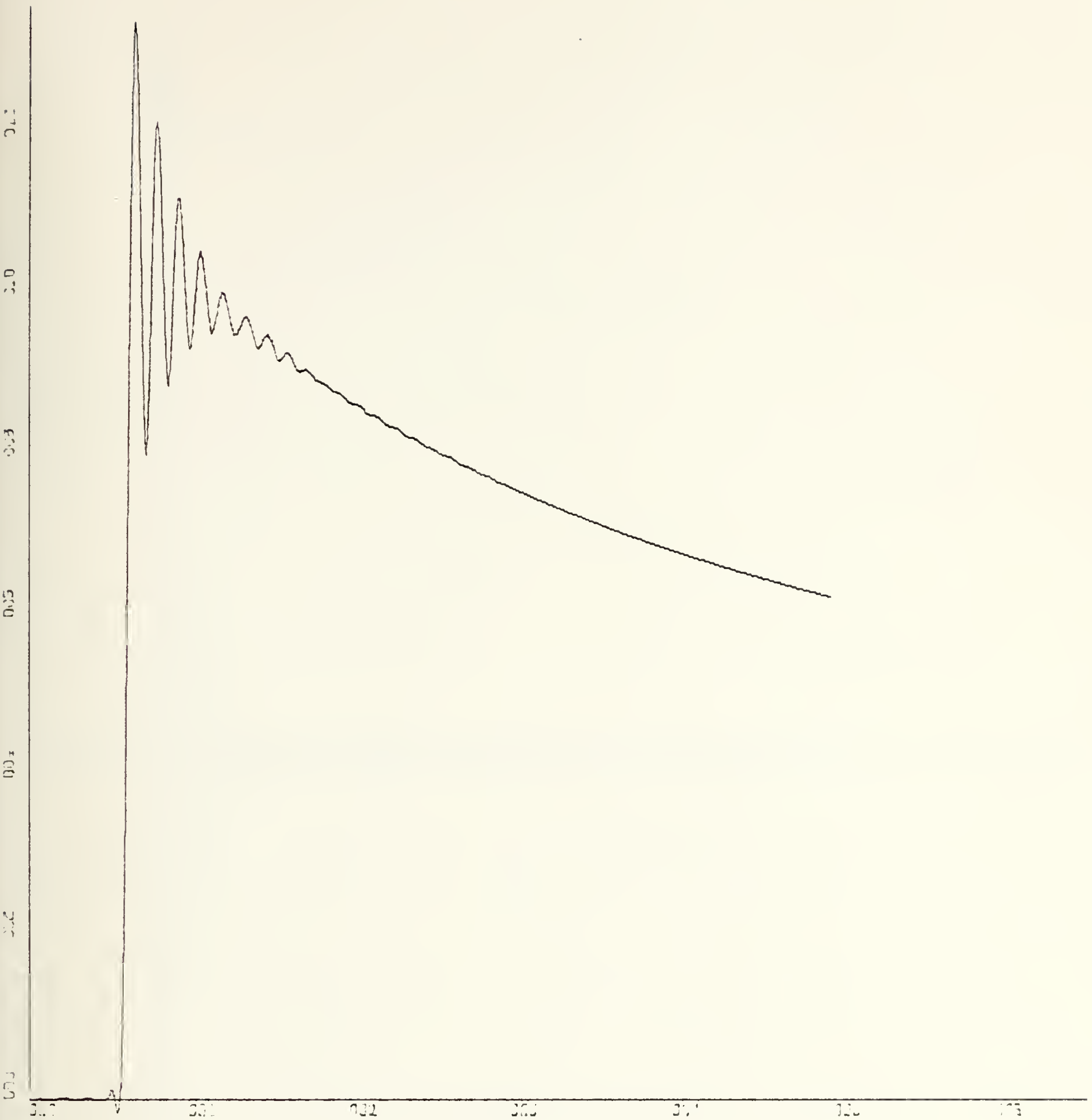
PLOT 75

for applied parameters see first page of this appendix



PLOT 76

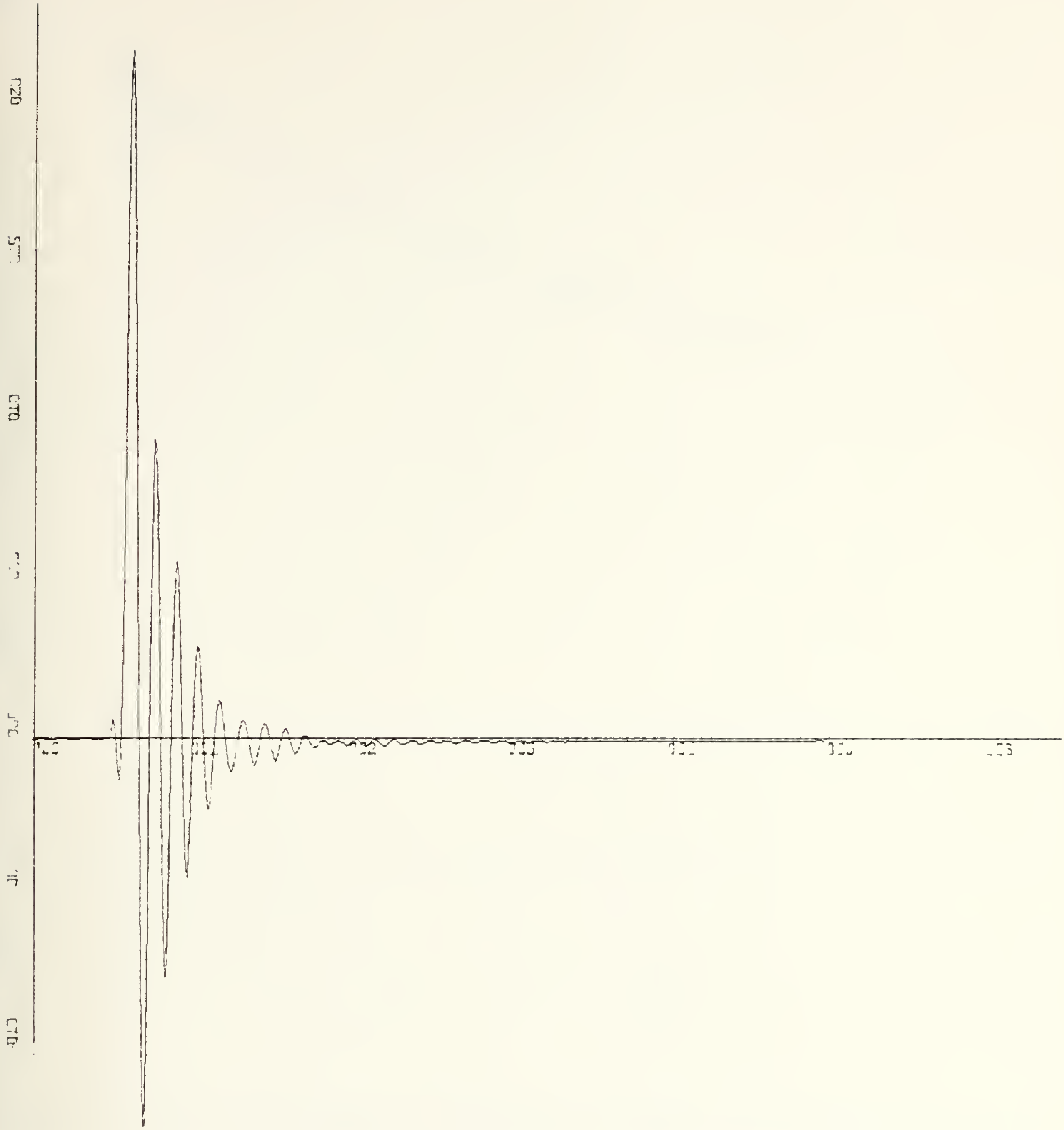
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
RGROK3 . TURN 20 KN . RUDM=15
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 77

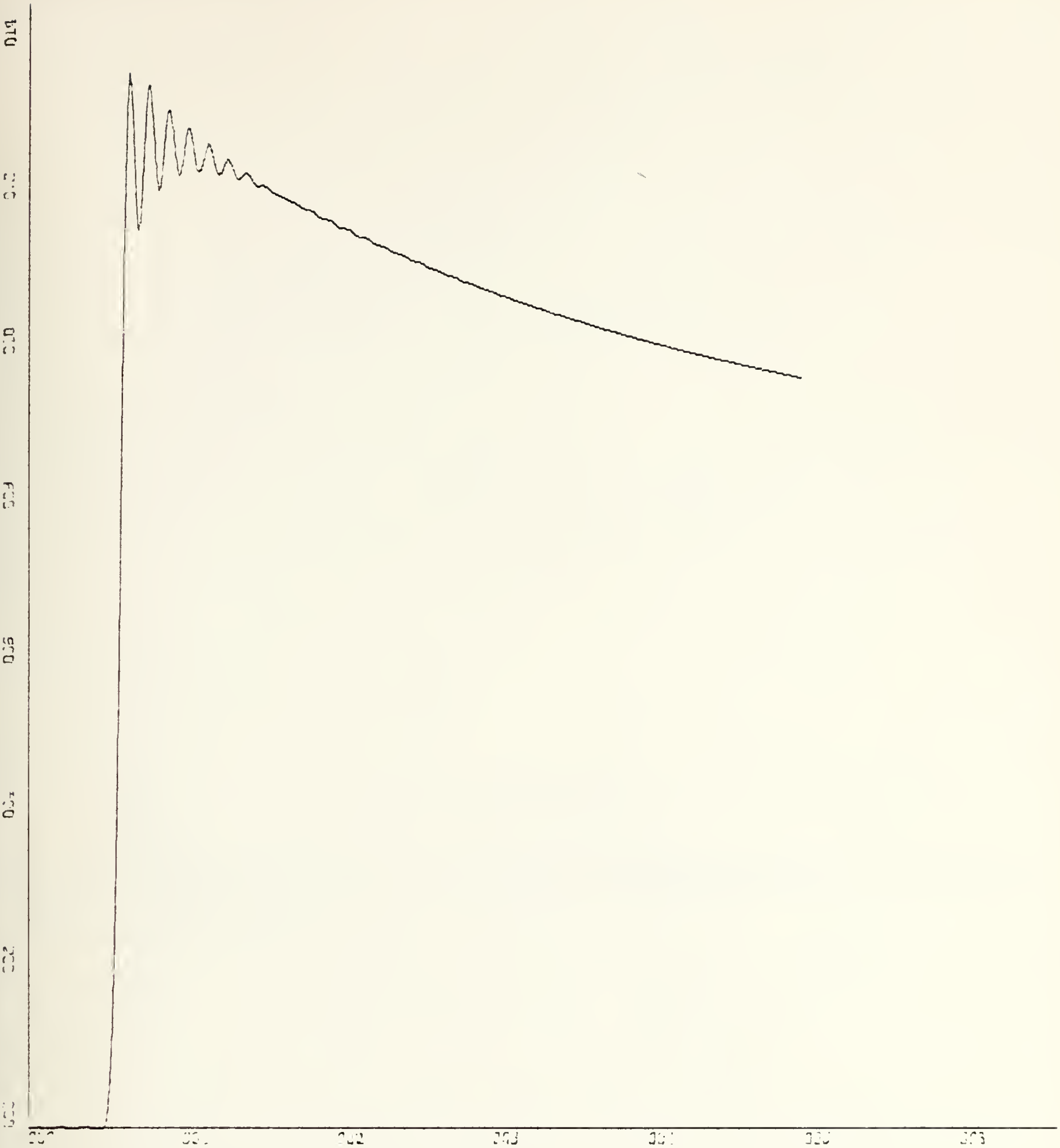
for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGROK3 . TURN 20 KN . RUDM=15
PLØT IS RØLL RATE VERSUS TIME

PLOT 78

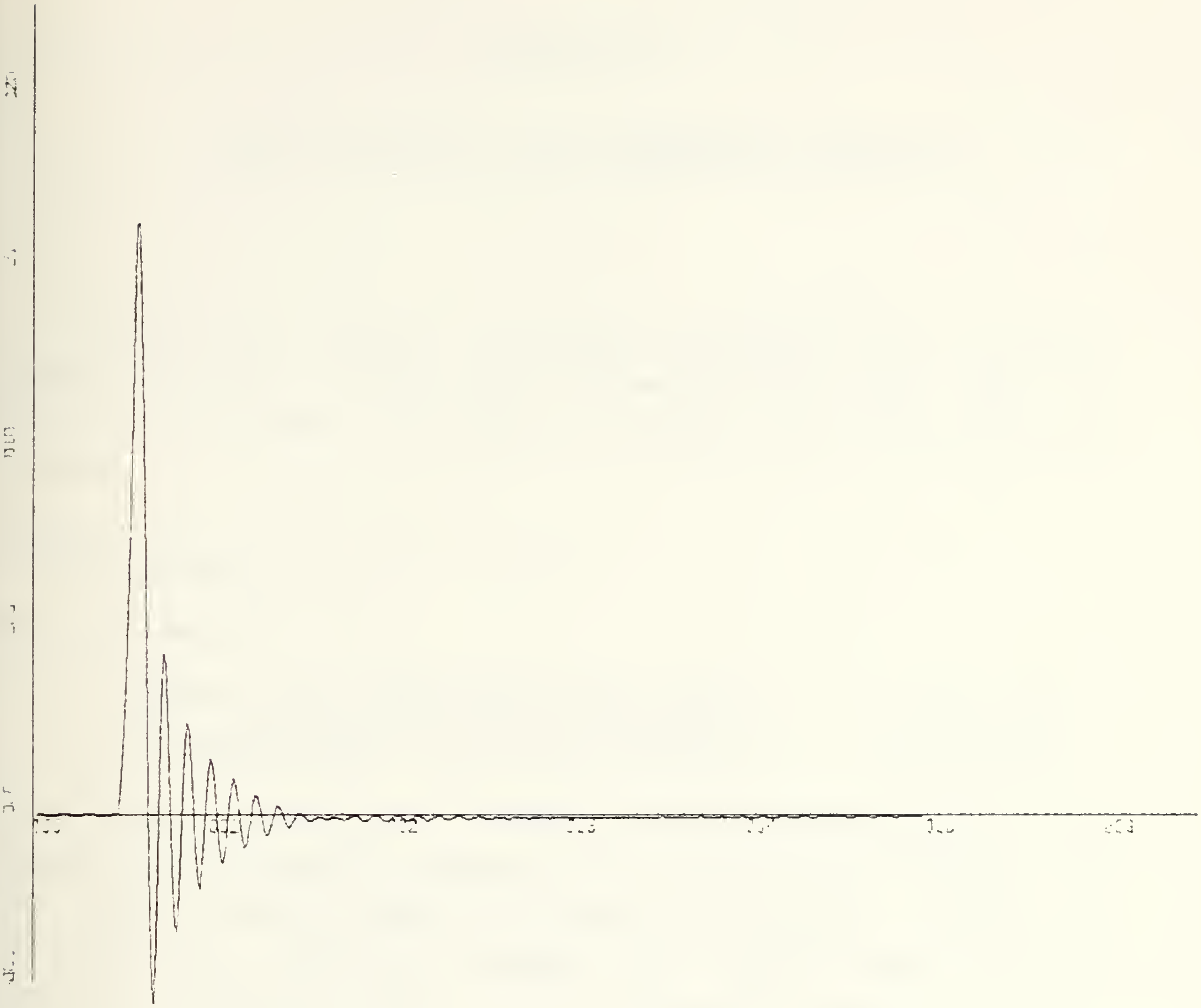
for applied parameters see first page of this appendix



X-SCALE 1.00E+01 UNITS INCH.
Y-SCALE 2.00E-01 UNITS INCH.
RCR1K3 . TURN 20 KN . RUDM=15
PLOT IS ROLL ANGLE VERSUS TIME

PLOT 79

for applied parameters see first page of this appendix



X-SCALE=1.00E+01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.
RGR1K3 . TURN 20 KN . RUDM=15
PLOT IS ROLL RATE VERSUS TIME

PLOT 80

for applied parameters see first page of this appendix

APPENDIX B

MODIFICATIONS OF THE SIMULATION PROGRAM

During the course of studies undertaken with the XR-3 Loads and Motion Program some statements have been added or changed in order to improve the work with the simulation program.

* MAIN program

The statements

```
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT              (MAIN0050)
      IF (MYTIME(DUM).LT.IQUIT) GO TO 12              (MAIN0661)
```

have been modified and added to the MAIN-program. The purpose of the second statement is to start the writing of the output values desired if computer time has reached the demanded time (jobcard) reduced by IQUIT which is the expected amount of time (in 10^{4} seconds) required to print the output. The user may input the desired value of IQUIT as the fourth parameter (I10-Format, columns 36-45) on the 107 data card. Default value for IQUIT is 600000 (60 seconds).

* Subroutine INCON

The added statements are

```
      IQUIT=600000                                    (INCN0881)
```

to set the default value and

```
      READ (5,2041) IQUIT                             (INCN1455)
```

to read the set value for IQUIT thereby overriding the default value.

* Subroutine RHS

In Menzel's version [Ref. 2] of the XR-3 Loads and Motions Program the entered craft's velocity UO (kn) is changed in Subroutine INCON to U (ft/sec) by

```
U = UO*1.6889                         (INCN4580)
```

and in Subroutine RHS transformed back to units in knots (RHS 1850) by

```
VEL = 0.5925*U .                      (RHS 1850)
```

From these two equations follows

```
VEL = 0.5925*UO*1.6889
```

and for UO=20 kn there results VEL = 20.0135 kn . But since it is desired that VEL=UO the statement has been corrected to

```
VEL = U/1.6889 .
```

Statements MAIN0840, RHS 1140 have been changed accordingly.

* Subroutine INTGRL

To this subroutine the statement

```
CALL COLFIL                           (INT 1021)
```

has been added in order to provide the output values already calculated to the user if the minimum time interval allowed in the integration process is undergone. Before this addition only the warning message

'DELTA TIME LESS THAN 1.0E-6 - - JOB STOPS'

appeared and the output values have been lost.

APPENDIX C

XR-3 LOADS AND MOTIONS PROGRAM

```
C
C     MAIN DECK
C
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,INT,XMI(10),YMI(7),IX,IY
      COMMON /CONST/ PI,RAD,U0
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,
     ATIP(25),TIS(25)
      COMMON /EQNCO/ NEQS,TCL(20),JQQ
      COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP
      COMMON / FROUDE / FN,FNCRIT
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /ROLL/ PHIMAX,TROLL
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUDANG,TIR(25)
      COMMON / VALOLD / YOLD(20)
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),CVCLW,NWAVE,BETA,
     1             FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2             ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR
      EQUIVALENCE               (VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      DIMENSION DUMMY(20)
C
      TC=1.0
      CN=1
      PI=4.*ATAN(1.)
      RAD=180./PI
      WRITE(6,100)
  100 FORMAT(1H1//35X,22H LISTING OF INPUT DECK  //)
   99 READ(44,101,END=104) DUMMY
  101 FORMAT(20A4)
  105 WRITE(6,102)DUMMY
      WRITE(5,101) DUMMY
  102 FORMAT(5X,20A4)
      GO TO 99
  104 REWIND 5
C
   11 CALL INCON(TIME)
C
      IF (IMM.EQ.3)  GO TO 605
      DO 10 J=1,20
```

```
   10 YOLD(J)=VAL(J+1)                                            MAIN0490
      GO TO 2                                                     MAIN0500
    1 CONTINUE                                                    MAIN0510
      TOLD=TIME                                                   MAIN0520
      PBBAR=PBBAR*(1.-DELT/TC)+DELT*(PB-PINF)/TC                  MAIN0530
      IF ( NWAVE.LE.0 )  GO TO 13                                 MAIN0540
      ZBAR=(1.-DELT/TC)*ZBAR+DELT*Z/TC                            MAIN0550
      PHIBAR=(1.-DELT/TC)*PHIBAR+DELT*PHI/TC                      MAIN0560
      THEBAR=(1.-DELT/TC)*THEBAR+DELT*THETA/TC                    MAIN0570
C                                                                 MAIN0580
      CALL WAVES(TIME)                                            MAIN0590
   13 CALL SIDEWL                                                 MAIN0600
      CALL PROP                                                   MAIN0610
      CALL RUDDER                                                 MAIN0620
      CALL AEROD                                                  MAIN0630
      CALL INTGRL(TIME)                                           MAIN0640
C                                                                 MAIN0650
      IF(TIME.GT.FTIME) GO TO 12                                  MAIN0660
      IF (MYTIME(DUM).LT.IQUIT) GO TO 12                          MAIN0661
      IF ( FN.GT.FNCRIT) GO TO 14                                 MAIN0670
      PRINT 505                                                   MAIN0680
      GO TO 12                                                    MAIN0690
   14 DELOLD=TIME-TOLD                                            MAIN0700
      PSI=PSI+DELOLD*R                                            MAIN0710
      X=X+DELOLD*(U*COS(PSI)-V*SIN(PSI))                          MAIN0720
      Y=Y+DELOLD*(U*SIN(PSI)+V*COS(PSI))                          MAIN0730
   15 IF (ABS(TIME-TPRINT) .LT. 1.E-6) GO TO 2                    MAIN0740
      GO TO 1                                                     MAIN0750
    2 CONTINUE                                                    MAIN0760
      IF(ITRAJ .EQ. 0) GOTO 16                                    MAIN0770
      DPHI=PHI*RAD                                                MAIN0780
      DPSI=PSI*RAD                                                MAIN0790
      DTHETA=THETA*RAD                                            MAIN0800
      DP=P*RAD                                                    MAIN0810
      DQ=Q*RAD                                                    MAIN0820
      DR=R*RAD                                                    MAIN0830
      VEL=0.5925*U                                                MAIN0840
      WRITE (6,500) TIME,VEL,V,W,DP,DQ,DR,Z,DPHI,DTHETA,X,Y,DPSI  MAIN0850
      BETS=(-V/U)*RAD                                             MAIN0860
      DELRS=RUDANG*RAD                                            MAIN0870
      WRITE(6,501) BETS,DELRS,FXP                                 MAIN0880
16    CONTINUE                                                    MAIN0890
      IMMTAG = (IMM+1)/2                                          MAIN0900
      IF ( IMMTAG .EQ. 1  .AND. TIME.GE.BTIME-1.E-8 )  IMT = 1    MAIN0910
      TPRINT=TPRINT+DELPNT                                        MAIN0920
      CN=1                                                        MAIN0930
      GO TO 1                                                     MAIN0940
C                                                                 MAIN0950
```

```
12   CALL COLFIL                                                        MAIN0960
C                                                                       MAIN0970
     IF (IMM.LT.1)  GO TO 11                                            MAIN0980
     IF (IMM.NE.1)  GO TO 605                                           MAIN0990
     END FILE IBMFIL                                                    MAIN1000
     GO TO 11                                                           MAIN1010
C                                                                       MAIN1020
605  CALL SAM                                                           MAIN1030
C                                                                       MAIN1040
     GO TO 11                                                           MAIN1050
C                                                                       MAIN1060
500  FORMAT(//10X,13HTIME (SEC) =  F6.2//10X,33HTRANSLATIONAL VELS (KTSMAIN1070
    1)/(FT/SEC) /10X,2HU= F6.2,5X,2HV= F6.2,5X,2HW= F6.3//10X,31HROTATIMAIN1080
    2ONAL VELOCITIES (DEG/SEC) /10X,2HP= F6.2,5X,2HQ= F6.2,5X,2HR= F6.2MAIN1090
    3//10X,30HDISPLACEMENTS (FT AND DEGREES) /10X,2HZ= F7.3,5X,4HPHI=   MAIN1100
    4F6.2,3X,6HTHETA= F6.2//10X,27HTRAJECTORY (FT AND DEGREES) /10X,    MAIN1110
    52HX= F8.2,4X,2HY= F8.2,4X,4HPSI= F8.2)                            MAIN1120
501  FORMAT(1H0,9X,23HSIDESLIP ANGLE (DEG) =   F8.2,10X,21HRUDDER ANGLEMAIN1130
    1 (DEG) =  F8.3,10X,15HTHRUST (LBS) =   F12.1)                      MAIN1140
505  FORMAT(///25X,28HCRAFT SPEED BELOW HUMP SPEED )                    MAIN1150
C                                                                       MAIN1160
     END                                                                MAIN1170
C                                                                       BLDA0010
     BLOCK DATA                                                         BLDA0020
C                                                                       BLDA0030
     COMMON /AIR/ Z1(4)                                                 BLDA0040
C   IN MAIN, INCON, SIDEWL, RHS, BOWSL, STNSL, FAN                      BLDA0050
     COMMON /BMCO/ Z2(25)                                               BLDA0060
C   IN MAIN, INCON, WAVES, SIDEWL, RHS, INTGRL                          BLDA0070
     COMMON /COLUMN / Z3(2)                                             BLDA0080
C   IN INCON, RHS, COLFIL                                               BLDA0090
     COMMON /CONST/ Z4(3)                                               BLDA0100
C   IN MAIN, INCON, WAVES, SIDEWL, PROP, RUDDER, RHS, BOWSL, STNSL      BLDA0110
     COMMON /CNTRL/ Z5(10)                                              BLDA0120
C   IN INCON, RHS                                                       BLDA0130
     COMMON /ENGINE/ Z6(107)                                            BLDA0140
C   IN MAIN, INCON, PROP, RHS                                           BLDA0150
     COMMON /EQNCO/ Z7(22)                                              BLDA0160
C   IN MAIN, INCON, INTGRL, COLFIL                                      BLDA0170
     COMMON /FAERO/ Z8(6)                                               BLDA0180
C   IN AEROD, RHS                                                       BLDA0190
     COMMON /FAIR/ Z9(2)                                                BLDA0200
C   IN INCON, AEROD                                                     BLDA0210
     COMMON /FANMAP/ Z10(262)                                           BLDA0220
C   IN INCON, RHS, FAN                                                  BLDA0230
     COMMON /FORBS/ Z11(7)                                              BLDA0240
C   IN RHS, BOWSL                                                       BLDA0250
```

```
      COMMON /FORSS/Z12(8)                                                    BLDA0260
C     IN RHS, STNSL                                                           BLDA0270
      COMMON /FPROP/ Z13(6)                                                   BLDA0280
C     IN MAIN, PROP, RHS                                                      BLDA0290
      COMMON /FROUDE/ Z14(2)                                                  BLDA0300
C     IN MAIN, INCON, RHS                                                     BLDA0310
      COMMON /FRUD/ Z15(6)                                                    BLDA0320
C     IN RUDDER, RHS                                                          BLDA0330
      COMMON /GBOW/ Z16(1)                                                    BLDA0340
C     IN INCON, RHS                                                           BLDA0350
      COMMON /GEOM/ Z17(138)                                                  BLDA0360
C     IN INCON, WAVES, SIDEWL, RHS, BOWSL, STNSL                              BLDA0370
      COMMON /GEOMBS/ Z18(62)                                                 BLDA0380
C     IN WAVES, RHS, BOWSL                                                    BLDA0390
      COMMON /GEOMSS/ Z19(62)                                                 BLDA0400
C     IN WAVES, RHS, STNSL                                                    BLDA0410
      COMMON /GEOMSW/ Z20(11)                                                 BLDA0420
C     IN INCON, SIDEWL                                                        BLDA0430
      COMMON /KSWTCH/ Z21(1)                                                  BLDA0440
C     IN SIDEWL, RHS, STNSL, INTGRL                                           BLDA0450
      COMMON /LEAKER/ Z22(4)                                                  BLDA0460
C     IN INCON, BOWSL, STNSL                                                  BLDA0470
      COMMON /MASSES/ Z23(817)                                                BLDA0480
C     IN INCON, WAVES, SIDEWL, RUDDER, RHS, BOWSL, STNSL, INTGRL              BLDA0490
      COMMON /MATRIX/ Z24(36)                                                 BLDA0500
C     IN INCON, RHS                                                           BLDA0510
      COMMON /MSIDW/ Z25(55)                                                  BLDA0520
C     IN SIDEWL, RHS                                                          BLDA0530
      COMMON /MWAVE/ Z26(12)                                                  BLDA0540
C     IN WAVES, RHS                                                           BLDA0550
      COMMON /OPTION/ Z27(5)                                                  ********
C     IN INCON, RHS                                                           BLDA0570
      COMMON /PLENUM/ Z28(4)                                                  BLDA0580
C     IN INCON, WAVES, SIDEWL, RHS                                            BLDA0590
      COMMON /PRIME/ Z29(5)                                                   BLDA0600
C     IN MAIN, INCON, SIDEWL, RHS, INTGRL                                     BLDA0610
      COMMON /PRTINT/ Z30(12)                                                 BLDA0620
C     IN MAIN, INCON, WAVES, SIDEWL, PROP, RUDDER, AEROD, RHS, BOWSL,         BLDA0630
C        STNSL, FAN, INTGRL                                                   BLDA0640
      COMMON /PWAVE/ Z31(2)                                                   BLDA0650
C     IN INCON, RHS                                                           BLDA0660
      COMMON /RISER/ Z32(1)                                                   BLDA0670
C     IN INCON, WAVES                                                         BLDA0680
      COMMON /ROLL/ Z33(2)                                                    BLDA0690
C     IN MAIN, INCON                                                          BLDA0700
      COMMON /RUDDR/ Z34(62)                                                  BLDA0710
C     IN MAIN, INCON, PROP, RUDDER, RHS                                       BLDA0720
      COMMON /SIDE/ Z35(22)                                                   BLDA0730
```

```
C     IN INCON, WAVES, SIDEWL, RHS                                       BLDA0740
        COMMON /SOFTBS/ Z36(20)                                          BLDA0750
C     IN INCON, RHS, BOWSL, FAN                                          BLDA0760
        COMMON /SOFTSS/ Z37(19)                                          BLDA0770
C     IN INCON, RHS, STNSL, FAN                                          BLDA0780
        COMMON /STABLE/ Z38(5)                                           BLDA0790
C     IN INCON, INTGRL                                                   BLDA0800
        COMMON /STSLR/ Z39(2)                                            BLDA0810
C     IN INCON, STNSL                                                    BLDA0820
        COMMON /VALOLD/ Z40(20)                                          BLDA0830
C     IN MAIN, INCON, RHS, STNSL, INTGRAL                                BLDA0840
        COMMON /VARBLE/ Z41(40)                                          BLDA0850
C     IN MAIN, INCON, WAVES, SIDEWL, PROP, RUDDER, AEROD, RHS, BOWSL,    BLDA0860
C        STNSL, FAN, INTGRL                                              BLDA0870
        COMMON /WAVE/ Z42(80)                                            BLDA0880
C     IN MAIN, INCON, WAVES, SIDEWL, RHS, BOWSL, STNSL                   BLDA0890
        COMMON /WAVEF / Z43(40)                                          BLDA0900
C     IN INCON                                                           BLDA0910
        COMMON /SLOPE/Z44(5)                                             BLDA0920
C     IN INCON, RHS, BOWSL                                               BLDA0930
        COMMON /PROMOD/ Z45(7)                                           BLDA0940
C     IN MAIN AND ALL SUBROUTINES                                        BLDA0950
C                                                                        BLDA0960
        DATA Z1/4*0.0/                                                   BLDA0970
        DATA Z2/25*0.0/                                                  BLDA0980
        DATA Z3/2*0.0/                                                   BLDA0990
        DATA Z4/3*0.0/                                                   BLDA1000
        DATA Z5/10*0.0/                                                  BLDA1010
        DATA Z6/107*0.0/                                                 BLDA1020
        DATA Z7/21*0.0/                                                  BLDA1030
        DATA Z8/6*0.0/                                                   BLDA1040
        DATA Z9/2*0.0/                                                   BLDA1050
        DATA Z10/262*0.0/                                                BLDA1060
        DATA Z11/7*0.0/                                                  BLDA1070
        DATA Z12/8*0.0/                                                  BLDA1080
        DATA Z13/6*0.0/                                                  BLDA1090
        DATA Z14/2*0.0/                                                  BLDA1100
        DATA Z15/6*0.0/                                                  BLDA1110
        DATA Z16/0.0/                                                    BLDA1120
        DATA Z17/138*0.0/                                                BLDA1130
        DATA Z18/62*0.0/                                                 BLDA1140
        DATA Z19/62*0.0/                                                 BLDA1150
        DATA Z20/11*0.0/                                                 BLDA1160
        DATA Z21/0.0/                                                    BLDA1170
        DATA Z22/4*0.0/                                                  BLDA1180
        DATA Z23/817*0.0/                                                BLDA1190
        DATA Z24/36*0.0/                                                 BLDA1200
        DATA Z25/55*0.0/                                                 BLDA1210
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      DATA Z26/12*0.0/                                                  BLDA1220
      DATA Z27/5*0.0/                                                   ********
      DATA Z28/4*0.0/                                                   BLDA1240
      DATA Z29/5*0.0/                                                   BLDA1250
      DATA Z30/12*0.0/                                                  BLDA1260
      DATA Z31/2*0.0/                                                   BLDA1270
      DATA Z32/0.0/                                                     BLDA1280
      DATA Z33/2*0.0/                                                   BLDA1290
      DATA Z34/62*0.0/                                                  BLDA1300
      DATA Z35/22*0.0/                                                  BLDA1310
      DATA Z36/20*0.0/                                                  BLDA1320
      DATA Z37/19*0.0/                                                  BLDA1330
      DATA Z38/5*0.0/                                                   BLDA1340
      DATA Z39/2*0.0/                                                   BLDA1350
      DATA Z40/20*0.0/                                                  BLDA1360
      DATA Z41/40*0.0/                                                  BLDA1370
      DATA Z42/80*0.0/                                                  BLDA1380
      DATA Z43/40*0.0/                                                  BLDA1390
      DATA Z44/5*0.0/                                                   BLDA1400
      DATA Z45/7*0.0/                                                   BLDA1410
C                                                                       BLDA1420
      END                                                               BLDA1430

C                                                                       AER 0010
      SUBROUTINE AEROD                                                  AER 0020
C                                                                       AER 0030
                                                                        AER 0040
      INTEGER ON                                                        AER 0050
      COMMON /FAERO/ FX,FY,FZ,FK,FM,FN                                  AER 0060
      COMMON /FAIR/ RHOA,XLAERO                                         AER 0070
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7  AER 0080
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  AER 0090
     -IRUC,IPROP,IAEROD,IRHS                                            AER 0100
      COMMON /VARBLE/ VAL(40)                                           AER 0110
      EQUIVALENCE               (VAL(2),U),(VAL(3),V),(VAL(4),W),       AER 0120
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     AER 0130
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),AER 0140
     3(VAL(24),PB)                                                      AER 0150
C                                                                       AER 0160
      QA=RHOA*U*U                                                       AER 0170
      QAL=QA*XLAERO                                                     AER 0180
      BETA=-V/U                                                         AER 0190
      BETASQ=BETA*BETA                                                  AER 0200
      FX=-(0.90*BETASQ+0.13)*QA                                         AER 0210
      FY=(0.0*BETASQ+0.53*BETA)*QA                                      AER 0220
      FZ=-(2.06*BETASQ+0.39)*QA                                         AER 0230
      FK=-(0.5*BETASQ+0.0*BETA)*QAL                                     AER 0240
      FM=(0.29*BETASQ+0.12)*QAL                                         AER 0250
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      FN=(0.0*BETASQ+0.076*BETA)*QAL
      IF (IAEROD.NE.ON) RETURN
                    WRITE(6,100) FX,FY,FZ,FK,FM,FN
C
  100 FORMAT(/10X,23HAERUD FX,FY,FZ,FK,FM,FN/6E15.4)
C
      RETURN
      END
C
      SUBROUTINE BOWSL
C
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT
      COMMON /CONST/ PI,RAD,U0
      COMMON /FORBS/ FX,FY,FZ,FK,FM,FN,CL
      COMMON /GEOM/ WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM,DELS(4,
     110),XCF,ZCP
      COMMON /GEOMBS/ DETABX(11),DETABT(11),ARM1B(10),ARM2B(10),DFBS(10)
     1,TSKIB(10)
      COMMON /LEAKER/ ALEAK,BLEAK,CFSS,CFBS
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,AM
     1I(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,I
     1RUD,IPROP,IAEROD,IRHS
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON /SLOPE/ WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS
      COMMON /SOFTBS/ XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAV
     1GE(10),CENCAB
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,FXWAV,FY
     1WAV,FZWAV,FKWAV,FMWAV,FNWAV,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PB
     2BAR
      DIMENSION ELSKID(11), WETLEN(11), BWSL(6,24), GAP(11), ELSKI(11),
     1CPFT(11), WTAB(6), ZTAB(6)
      DATA NPTS,IBS/6,0/
      DATA WTAB/0.0,3.75,5.42,6.67,7.5,8.42/
      DATA ZTAB/3.75,4.00,4.42,4.83,5.25,5.67/
      DATA ENU,UWSKI,CLSKI,HINGHT/1.28E-05,0.0,1.5708,1.875/
      DATA BWSL/0.0,3.8,6.9,9.9,12.3,15.0,0.0,4.1,7.3,10.5,13.2,15.7,0.0
     1,4.3,7.7,11.0,13.7,16.7,0.0,4.7,8.2,11.5,14.5,17.4,0.0,5.2,8.9,12.
     24,15.4,18.3,0.0,5.5,9.6,13.3,16.1,19.6,0.0,5.8,9.9,13.8,17.1,20.6,
     30.0,6.1,10.6,14.7,18.4,21.9,0.0,6.4,11.0,15.3,19.3,23.3,0.0,6.6,11
     4.7,16.4,20.5,24.5,0.0,6.9,12.3,17.6,22.1,25.7,0.0,7.2,13.5,19.6,24
     5.1,28.3,0.0,8.2,15.3,21.7,26.3,31.3,0.0,9.6,17.5,24.2,29.7,34.6,0.
     60,11.9,20.0,26.7,32.3,38.0,0.0,14.0,22.5,30.0,35.8,41.0,0.0,17.5,2
     75.5,32.5,39.7,44.5,0.0,21.0,30.0,37.4,42.0,47.0,0.0,24.6,33.7,41.0
     8,45.0,48.7,0.0,29.4,38.5,45.0,48.7,48.7,0.0,33.0,45.0,48.7,48.7,48
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9.7,0.0,40.0,48.7,48.7,48.7,48.7,0.0,48.7,48.7,48.7,48.7,48.7,0.0,4
$8.7,48.7,48.7,48.7,48.7/
 DATA CORLEN/3.75/
 EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VA
1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VA
2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)
3, (VAL(24),PB)
C
 DO 1 J=1,11
 GAP(J) = 0.0
 ELSKI(J) = 0.0
 WETLEN(J) = 0.0
 ELSKID(J) = 0.0
1 CONTINUE
 ALBS = 0.0
 FX = 0.0
 FZ = 0.0
 FK = 0.0
 FM = 0.0
 FN = 0.0
 DELPBG = PBS-PB
 IF (DELPBG.LT.0.0) DELPBG=0.0
 PBAR = PB-PINF
 DELP = PBAR
 IF (DELP.LT.0.0) DELP=0.0
 ARGO = ELMAXB/CORLEN
 ANGO = ARSIN(ARGO)
 X1 = XBS+ZBS*THETA-CORLEN*COS(ANGO)
 Z1 = -Z-ZBS+XBS*THETA-ELMAXB*COS(THETA)
 DPTHFT = (5.5/(1.+(U/25.))**2.0)/12.0
 IF (CENCAB.GT.1.1875) CENCAB=1.1875
 N = NSTA(3)
 DO 3 K=1,N
 DPFT(K) = DPTHFT
 ELSKI(K) = (ETA(3,K)-DETABX(K)*(XX(3,K)-X1)-Z1)+YY(3,K)*PHI+XLXPWV
1*WATSLP
 IF (ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT
 IF ((HINGHT-ELSKI(K)+DPFT(K)).GE.ELMAXB) DPFT(K)=ELMAXB-HINGHT+ELS
1KI(K)
 IF (DPFT(K).LT.0.0) DPFT(K)=0.0
 ELSKID(K) = (ELSKI(K)-DPFT(K))*12.0
 IF ((HINGHT-ELSKID(K)/12.0).GE.ELMAXB) ELSKID(K)=(HINGHT-ELMAXB)*1
12.0
 DPIN = DPFT(K)*12.0
 MM = DPIN
 MM1 = MM+1
 MM2 = MM1+1
 DINC = DPIN-MM
```

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      GAP(K) = -ELSKI(K)+(HINGHT-ELMAXB)                                BWSL0880
      IF (GAP(K).LT.0.0) GAP(K)=0.0                                     BWSL0890
      IF (ELSKID(K).GE.0.) GO TO 2                                      BWSL0900
      WETLEN(K) = ELSKI(K)                                              BWSL0910
      GO TO 3                                                           BWSL0920
    2 MM3 = ELSKID(K)                                                   BWSL0930
      MM4 = MM3+1                                                       BWSL0940
      MM5 = MM4+1                                                       BWSL0950
      DLINC = ELSKID(K)-MM3                                             BWSL0960
      BWSL1 = BWSL(MM1,MM4)                                             BWSL0970
      BWSL2 = BWSL(MM1,MM5)                                             BWSL0980
      BWSL3 = BWSL(MM2,MM4)                                             BWSL0990
      BWSL4 = BWSL(MM2,MM5)                                             BWSL1000
      BWSLA1 = (BWSL2-BWSL1)*DLINC+BWSL1                                BWSL1010
      BWSLA2 = (BWSL4-BWSL3)*DLINC+BWSL3                                BWSL1020
      WETLEN(K) = ((BWSLA2-BWSLA1)*DINC+BWSLA1)/12.0                    BWSL1030
    3 CONTINUE                                                          BWSL1040
      N = NSTA(3)-1                                                     BWSL1050
      DO 10 J=1,N                                                       BWSL1060
      WETLAV = (WETLEN(J+1)+WETLEN(J))/2.0                              BWSL1070
      IF (WETLAV.LE.0.001) GO TO 8                                      BWSL1080
      DPFTAV = (DPFT(J+1)+DPFT(J))/2.0                                  BWSL1090
      ELSKIA = (ELSKI(J+1)+ELSKI(J))/2.0                                BWSL1100
      ELSKDA = (ELSKID(J+1)+ELSKID(J))/24.0                             BWSL1110
      SEALHT = HINGHT-ELSKDA                                            BWSL1120
      DIFF = 2.0*CENCAB-(SEALHT+0.5)                                    BWSL1130
      IF (DIFF.GT.0.5) DIFF=0.5                                         BWSL1140
      ARM1B(J) = X1+WETLAV/2.0                                          BWSL1150
      ARM2B(J) = ZS-ELSKIA+DPFTAV/2.0                                   BWSL1160
      IF (DIFF.GE.0.25) GO TO 4                                         BWSL1170
      CFBS(J) = -DELP*DELYBS*WETLAV                                     BWSL1180
      GO TO 7                                                           BWSL1190
    4 FORLEN = XBF-WETLAV                                               BWSL1200
      IF (FORLEN.EQ.0.0) GO TO 5                                        BWSL1210
      ARGW = (HINGHT-ELSKIA)/FORLEN                                     BWSL1220
      IF (ARGW.GT.1.0) ARGW=1.0                                         BWSL1230
      ANGW = ARSIN(ARGW)                                                BWSL1240
      FORCOS = COS(ANGW)                                                BWSL1250
      GO TO 6                                                           BWSL1260
    5 FORCOS = 0.0                                                      BWSL1270
    6 CFBS(J) = -DELP*DELYBS*WETLAV-DELP*FORLEN*DELYBS*FORCOS*((FORLEN*0BWSL1280
     1.5*FORCOS)/(FORLEN*FORCOS+WETLAV/2.0))*((DIFF-0.25)*4.0)          BWSL1290
    7 ARG = 0.5*RHO*U*U*WETLAV*DELYBS                                   BWSL1300
      RESKI = U*WETLAV/ENU                                              BWSL1310
      CDTSKI = 0.427/(ALOG10(RESKI)-0.407)**2.64                        BWSL1320
      TSKIB(J) = -ARG*CDTSKI                                            BWSL1330
      GO TO 9                                                           BWSL1340
    8 CFBS(J) = 0.0                                                     BWSL1350
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      TSKIB(J) = 0.0                                                    BWSL1360
    9 CONTINUE                                                          BWSL1370
      FX = FX+TSKIB(J)                                                  BWSL1380
      FZ = FZ+DFBS(J)                                                   BWSL1390
      FK = FK+DFBS(J)*YAVGB(J)                                          BWSL1400
      FM = FM-DFBS(J)*ARM1B(J)+TSKIB(J)*ARM2B(J)                        BWSL1410
      FN = FN-TSKIB(J)*YAVGB(J)                                         BWSL1420
      ALBS = ALBS+(GAP(J)+GAP(J+1))*DELYBS/2.0                          BWSL1430
   10 CONTINUE                                                          BWSL1440
      ALBS = ALBS+BLEAK                                                 BWSL1450
      SQFAC = SQRT(2.*ABS(PBAR)/RHOINF)                                 BWSL1460
      QL = CFBS*ALBS*SQFAC*SIGN(1.,PBAR)                                BWSL1470
      IF (IBOWSL.NE.ON) RETURN                                          BWSL1480
      WRITE (6,11) GAP,WETLEN,FX,FY,FZ,FK,FM,FN                         BWSL1490
C                                                                       BWSL1500
   11 FORMAT (//10X,8HBOW SEAL/26H GAP (FT.) (PORT TO STBD.)/11F10.5/28HBWSL1510
     1 WETLEN(FT.) (PORT TO STBD.)/11F10.5/10X,23HBOWSL FX,FY,FZ,FK,FM,FBWSL1520
     2N/6E15.4)                                                         BWSL1530
C                                                                       BWSL1540
      RETURN                                                            BWSL1550
      END                                                               BWSL1560
C                                                                       CFL 0010
      SUBROUTINE COLFIL                                                 CFL 0020
C                                                                       CFL 0030
      COMMON/AXIS/NXYS(26)                                              CFL 0040
      COMMON/COLUMN/IVERT,ILATRL                                        CFL 0050
      COMMON /CURVE/NCURV(10)                                           CFL 0060
      COMMON/EQNCO/ NEQS,TOL(20),JQQ                                    CFL 0070
      COMMON/GRAF/NGRAF,NDRW                                            CFL 0080
      COMMON /HEADG/TICRD(6)                                            CFL 0090
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7. CFL 0100
      COMMON/STEP/ STEP2                                                CFL 0110
      COMMON /SUM/ ISUM1(8),ISUM2(8)                                    CFL 0120
      REAL*8 TICRD                                                      CFL 0130
      REAL LABEL                                                        CFL 0140
      REAL LAB(4)/'    ','   1','   2','   3'/                          CFL 0150
      REAL*8 NAMES(52)/'TIME    ','        ','AIR MASS',' (BMASS)','Z DICFL 0160
     1SPLA','CEMENT  ','PITCH AN','GLE     ','PLENUM P','RESSURE ','BOW CFL 0170
     2ACCE','LERATION','C.G.ACCE','LERATION','FAN POWE','R(IDEAL)','BOWCFL 0180
     3 SEAL','PRESSURE','STN SEAL','PRESSURE','    WAVE ','HEIGHT  ','SPECFL 0190
     4ED TH','RU WATER','ROLL RAT','E       ','PLENUM V','OLUME   ','X DCFL 0200
     5ISPLA','CEMENT  ','Y DISPLA','CEMENT  ','AIR FLOW',' IN     ','AIRCFL 0210
     6 FLOW',' OUT    ','NET FORC','E X DIR ','WAVE FOR','CE X DIR','THRCFL 0220
     7UST S','TARBOARD','THRUST P','ORT SIDE','  PITCH ','RATE    ','STECFL 0230
     8RN SE','AL LIFT ','STERN SE','AL DRAG ','  ROLL A','NGLE    '/   CFL 0240
      REAL*8 TITLE(12)                                                  CFL 0250
      REAL*8 LINE2(2)/'PLOT IS ',' VERSUS '/                            CFL 0260
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      REAL*8 NAMEX(2),NAMEY(2),INAME(16)                                CFL 0270
      EQUIVALENCE (TITLE(1),TICRD(1)),(TITLE(2),TICRD(2)),(TITLE(3),TI  CFL 0280
     1CRD(3)),(TITLE(4),TICRD(4)),(TITLE(5),TICRD(5)),(TITLE(6),TICRD(  CFL 0290
     26))                                                               CFL 0300
      DIMENSION PVQQ(26),XOUT(900),YOUT(900),AFILE(8)                   CFL 0310
      DIMENSION THSTS(1), THSTP(1)                                      CFL 0320
      EQUIVALENCE (PVQQ(1),TIME),(PVQQ(2),BMASS),(PVQQ(3),Z),(PVQQ(4),THCFL 0330
     1ETA),(PVQQ(5),PBAR),(PVQQ(6),BOWACC),(PVQQ(7),ACC),(PVQQ(8),FANPWRCFL 0340
     2),(PVQQ(9),PBARB),(PVQQ(10),PBARS),(PVQQ(11),ETA),(PVQQ(12),U),(PVCFL 0350
     3QQ(13),PDEG),(PVQQ(14),VOLP),(PVQQ(15),X),(PVQQ(16),Y),(PVQQ(17),QCFL 0360
     4IN),(PVQQ(18),QOUT),(PVQQ(19),GFXXX),(PVQQ(20),FXPWAV),(PVQQ(21),TCFL 0370
     5HSTS(1)),(PVQQ(22),THSTP(1)),(PVQQ(23),QDEG),(PVQQ(24),FZSS),(PVQQCFL 0380
     6(25),FXSS),(PVQQ(26),PHI)                                         CFL 0390
C                                                                       CFL 0400
      IF(JQQ.NE.2) GO TO 1                                              CFL 0410
      WRITE(6,777) STEP2                                                CFL 0420
  777 FORMAT('0',4X,'THIS RUN USED VARIABLE STEP SIZE',/,'0',4X,'THE MINCFL 0430
     1IMUM STEPSIZE RECORDED DURING THE RUN WAS',2X,E30.5)              CFL 0440
    1 ENDFILE 1                                                         CFL 0450
      REWIND 1                                                          CFL 0460
      TITLE(7)=LINE2(1)                                                 CFL 0470
      TITLE(10)=LINE2(2)                                                CFL 0480
      IF(NGRAF.EQ.0) GO TO 11                                           CFL 0490
      J=1                                                               CFL 0500
      NGF=NGRAF                                                         CFL 0510
      INDEX=NGRAF*2                                                     CFL 0520
      DO 19 I=1,INDEX,2                                                 CFL 0530
      INDX=NXYS(I)                                                      CFL 0540
      INDY=NXYS(I+1)                                                    CFL 0550
      IQ=0                                                              CFL 0560
    7 READ(1,END=8)TIME,BMASS,Z,THETA,PBAR,BOWACC,ACC,FANPWR,PBARB,PBARSCFL 0570
     1,ETA,U,PDEG,VOLP,X,Y,QIN,QOUT,GFXXX,FXPWAV,THSTS(1),THSTP(1),QDEG,CFL 0580
     2FZSS,FXSS,PHI                                                     CFL 0590
      IF(IQ.GE.900) GO TO 8                                             CFL 0600
      IQ=IQ+1                                                           CFL 0610
      XOUT(IQ)=PVQQ(INDX)                                               CFL 0620
      YOUT(IQ)=PVQQ(INDY)                                               CFL 0630
      GO TO 7                                                           CFL 0640
    8 REWIND 1                                                          CFL 0650
      INX=INDX*2                                                        CFL 0660
      INY=INDY*2                                                        CFL 0670
      NAMEX(1)=NAMES(INX-1)                                             CFL 0680
      NAMEX(2)=NAMES(INX)                                               CFL 0690
      NAMEY(1)=NAMES(INY-1)                                             CFL 0700
      NAMEY(2)=NAMES(INY)                                               CFL 0710
      IF(NDRW.EQ.1) GO TO 20                                            CFL 0720
C                                                                       CFL 0730
      CALL FLCTP(XOUT,YOUT,-IQ,0)                                       CFL 0740
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C
      WRITE(6,301) NAMEX,NAMEY
  301 FORMAT(' ',20X,2A8,' IS THE INDEPENDENT VARIABLE AND ',2A8,' THE D
     1EPENDENT VARIABLE')
      GO TO 19
   20 TITLE(8)=NAMEY(1)
      TITLE(9)=NAMEY(2)
      TITLE(11)=NAMEX(1)
      TITLE(12)=NAMEX(2)
      NCUR=NCURV(J)
      IF(NCUR.NE.0) GO TO 25
      LABEL=LAB(1)
C
      CALL DRAW(IQ,XOUT,YOUT,NCUR,0,LABEL,TITLE,0,0,0,0,0,0,8,8,0,LAST)
C
      J=J+1
      GO TO 19
   25 WRITE(2)IQ,NCUR,NGF,LABEL,(TITLE(K),K=1,12),(XOUT(L),YOUT(L),L=1,I
     1Q)
      NGF=NGF-1
   19 CONTINUE
      IF((NGF.EQ.0).AND.(NCUR.EQ.3)) GO TO 26
   11 IF(IVERT.NE.1) GO TO 14
      WRITE(6,100)
  100 FORMAT('0',50X,'***SUMMARY ONE***',/,'0')
      K=0
      DO 31 I=1,8
      IF(ISUM1(I).NE.0) K=K+1
   31 CONTINUE
      NUM1=K
      IF(K.EQ.0) GO TO 14
      N=K*2
      J=1
      DO 33 I=1,NUM1
      IDEX=ISUM1(I)*2
      INAME(J)=NAMES(IDEX-1)
      INAME(J+1)=NAMES(IDEX)
      J=J+2
   33 CONTINUE
       WRITE(6,300)(INAME(I),I=1,N)
  300 FORMAT('0',16A8)
      GO TO 4
   26 ENDFILE 2
      REWIND 2
      NGF=NGRAF
      J=1
   27 READ(2,END=38)IQ,NCUR,NGRAF,LABEL,(TITLE(K),K=1,12),(XOUT(L),YOUT(
     1L),L=1,IQ)
```

```
      IF((NGF.EQ.NGRAF).AND.(NCUR.EQ.J)) GO TO 29
      GO TO 27
   29 LABEL=LAB(J+1)
C
      CALL DRAW(IC,XOUT,YOUT,NCUR,0,LABEL,TITLE,0,0,0,0,0,0,8,8,0,LAST)
C
      REWIND 2
      J=J+1
      IF(J.EQ.4) GO TO 38
      GO TO 27
   38 NGF=NGF-1
      IF(NGF.EQ.0) GO TO 11
      J=1
      GO TO 27
    4 READ(1,END=13)(PVQQ(I),I=1,26)
      DO 35 I=1,NUM1
      J=ISUM1(I)
   35 AFILE(I)=PVQQ(J)
      WRITE(6,400)(AFILE(I),I=1,NUM1)
400   FORMAT('0',8(3X,F10.4,3X))
      GO TO 4
   13 REWIND 1
   14 IF(ILATRL.NE.1) GO TO 17
      WRITE(6,200)
  200 FORMAT('0',50X,'***SUMMARY TWO***',/,'0')
      K=0
      DO 32 I=1,8
      IF(ISUM2(I).NE.0) K=K+1
   32 CONTINUE
      NUM2=K
      IF(K.EQ.0) GO TO 16
      N=K*2
      J=1
      DO 34 I=1,NUM2
      IDEX=ISUM2(I)*2
      INAME(J)=NAMES(IDEX-1)
      INAME(J+1)=NAMES(IDEX)
      J=J+2
   34 CONTINUE
       WRITE(6,300)(INAME(I),I=1,N)
   23 READ(1,END=16)(PVQQ(I),I=1,26)
      DO 36 I=1,NUM2
      J=ISUM2(I)
   36 AFILE(I)=PVQQ(J)
      WRITE(6,400)(AFILE(I),I=1,NUM2)
      GO TO 23
   16 REWIND 1
   17 RETURN
```

```
      END                                                               CFL 1710
C                                                                       DMV 0010
      SUBROUTINE DMINV (A,N,D)                                          DMV 0020
C                                                                       DMV 0030
      DIMENSION A(6,6),PIVOT(6)                                         DMV 0040
      DIMENSION IPVOT(6),INDEX(6,2)                                     DMV 0050
      EQUIVALENCE (IROW,JROW),(ICOL,JCOL)                               DMV 0060
C                                                                       DMV 0070
      D=1.0                                                             DMV 0080
      DO 17 J=1,N                                                       DMV 0090
      IPVOT(J)=0                                                        DMV 0100
   17 CONTINUE                                                          DMV 0110
      DO 135 I=1,N                                                      DMV 0120
      T=0.0                                                             DMV 0130
        DO 9 J=1,N                                                      DMV 0140
      IF(IPVOT(J)-1) 13,9,13                                            DMV 0150
   13 DO 23 K=1,N                                                       DMV 0160
      IF(IPVOT(K)-1) 43,23,81                                           DMV 0170
   43 IF (ABS(T)-ABS(A(J,K))) 83,23,23                                  DMV 0180
   83 IROW=J                                                            DMV 0190
      ICOL=K                                                            DMV 0200
      T=A(J,K)                                                          DMV 0210
   23 CONTINUE                                                          DMV 0220
    9 CONTINUE                                                          DMV 0230
      IPVOT(ICOL)=IPVOT(ICOL)+1                                         DMV 0240
      IF(IROW-ICOL) 73,109,73                                           DMV 0250
   73 D=-D                                                              DMV 0260
      DO 12 L=1,N                                                       DMV 0270
      T=A(IROW,L)                                                       DMV 0280
      A(IROW,L)=A(ICOL,L)                                               DMV 0290
      A(ICOL,L)=T                                                       DMV 0300
   12 CONTINUE                                                          DMV 0310
  109 INDEX(I,1)=IROW                                                   DMV 0320
      INDEX(I,2)=ICOL                                                   DMV 0330
      PIVOT(I)=A(ICOL,ICOL)                                             DMV 0340
      D=D*PIVOT(I)                                                      DMV 0350
      A(ICOL,ICOL)=1.0                                                  DMV 0360
      DO 205 L=1,N                                                      DMV 0370
      A(ICOL,L)=A(ICOL,L)/PIVOT(I)                                      DMV 0380
  205 CONTINUE                                                          DMV 0390
      DO 134 LI=1,N                                                     DMV 0400
      IF(LI-ICOL) 21,134,21                                             DMV 0410
   21 T=A(LI,ICOL)                                                      DMV 0420
      A(LI,ICOL)=0.0                                                    DMV 0430
      DO 89 L=1,N                                                       DMV 0440
      A(LI,L)=A(LI,L)-A(ICOL,L)*T                                       DMV 0450
   89 CONTINUE                                                          DMV 0460
```

```
  134 CONTINUE                                                                DMV 0470
  135 CONTINUE                                                                DMV 0480
      DO 3 I=1,N                                                              DMV 0490
      L=N-I+1                                                                 DMV 0500
      IF(INDEX(L,1)-INDEX(L,2)) 19,3,19                                       DMV 0510
   19 JROW=INDEX(L,1)                                                         DMV 0520
      JCOL=INDEX(L,2)                                                         DMV 0530
      DO 549 K=1,N                                                            DMV 0540
      T=A(K,JROW)                                                             DMV 0550
      A(K,JROW)=A(K,JCOL)                                                     DMV 0560
      A(K,JCOL)=T                                                             DMV 0570
  549 CONTINUE                                                                DMV 0580
    3 CONTINUE                                                                DMV 0590
C                                                                             DMV 0600
   81 RETURN                                                                  DMV 0610
      END                                                                     DMV 0620

C                                                                             FAN 0010
      SUBROUTINE FAN                                                          FAN 0020
C                                                                             FAN 0030
      INTEGER ON                                                              FAN 0040
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT                                      FAN 0050
      COMMON /FANMAP/ CIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,ENFAN 0060
     1SFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS,PBFAN(25),PMFAN(25),PSFAN(2FAN 0070
     25),TMEB(25),DELB(25),NB,TMES(25),DELS(25),NS                            FAN 0080
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7   FAN 0090
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IFAN 0100
     1RUD,IPROP,IAEROD,IRHS                                                   FAN 0110
      COMMON /SOFTBS/ XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVFAN 0120
     1GE(10)                                                                  FAN 0130
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS,ELMAXS,YAVFAN 0140
     1GS(10)                                                                  FAN 0150
      COMMON /VARBLE/ VAL(40)                                                 FAN 0160
      DIMENSION QB(1), QM(1), QS(1), PBOW(1), PM(1), PS(1), HP(8)        FAN 0170
      EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VAFAN 0180
     1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VAFAN 0190
     2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)FAN 0200
     3, (VAL(24),PB)                                                          FAN 0210
      EQUIVALENCE (VAL(18),FANPWR)                                            FAN 0220
      EQUIVALENCE (VAL(35),PBARB),(VAL(36),PBARS)                             ********
      EQUIVALENCE (QBFAN(1),QB(1)), (QMFAN(1),QM(1)), (QSFAN(1),QS(1)),  FAN 0230
     1(PBFAN(1),PBOW(1)), (PMFAN(1),PM(1)), (PSFAN(1),PS(1))                FAN 0240
      DATA HP/2.9,2.3,1.95,1.77,1.85,2.05,1.93,1.62/                          FAN 0250
C                                                                             FAN 0260
      BRAT = 8000/BRPM                                                        FAN 0270
      EMRAT = 8000/EMRPM                                                      FAN 0280
      SRAT = 8000/SRPM                                                        FAN 0290
      TL = VAL(1)                                                             FAN 0300
```

```
      IF (NB.EQ.0.0) GO TO 1
      DPBS = FG1(TL,NB,TMEB,DELB,ILB)
      PBS = PB+DPBS
    1 IF (NS.EQ.0.0) GO TO 2
      DPSS = FG1(TL,NS,TMES,DELS,ILS)
      PSS = PB+DPSS
    2 CONTINUE
      PB1 = PBS-PINF
      PB2 = PB-PINF
      PB3 = PSS-PINF
      PBARB = PB1*BRAT**2
      PBARM = PB2*EMRAT**2
      PBARS = PB3*SRAT**2
      QBOW = ENBFAN*FG1(PBARB,NPTSB,PBOW,QB,IB)/BRAT
      QMAIN = ENMFAN*FG1(PBARM,NPTSM,PM,QM,IM)/EMRAT
      QSTN = ENSFAN*FG1(PBARS,NPTSS,PS,QS,IS)/SRAT
      QIN = QBOW+QMAIN+QSTN
      MB1 = (QBOW/ENBFAN+5.0)/5.0
      MB2 = MB1+1
      MB3 = MB2+1
      BINC = ((QBOW/ENBFAN+5.0)-MB1*5.0)/5.0
      BFANHP = ((HP(MB3)-HP(MB2))*BINC+HP(MB2))*ENBFAN*(1./BRAT)**3.0
      MS1 = (QSTN/ENSFAN+5.0)/5.0
      MS2 = MS1+1
      MS3 = MS2+1
      STINC = ((QSTN/ENSFAN+5.0)-MS1*5.0)/5.0
      SFANHP = ((HP(MS3)-HP(MS2))*STINC+HP(MS2))*ENSFAN*(1./SRAT)**3.0
      MM1 = (QMAIN/ENMFAN+5.0)/5.0
      MM2 = MM1+1
      MM3 = MM2+1
      PLINC = ((QMAIN/ENMFAN+5.0)-MM1*5.0)/5.0
      PFANHP = ((HP(MM3)-HP(MM2))*PLINC+HP(MM2))*ENMFAN*(1./EMRAT)**3.0
      RELPWR = PFANHP+BFANHP+SFANHP
      FANPWR = (QBOW*PB1+QMAIN*PB2+QSTN*PB3)/550.
      FANEFF = FANPWR/RELPWR
      IF (IRHS.NE.CN) RETURN
      WRITE (6,3) QBOW,QMAIN,QSTN,PBARB,PBARM,PBARS,RELPWR,FANPWR,FANEFF
C
    3 FORMAT (//4H FAN/32H Q - BOW,MAIN,STERN (CU FT /SEC)3F12.1/28H DEL
     1P - BOW,MAIN,STERN (PSF)3F11.2/60H ACTUAL FAN POWER REQUIRED(HP),
     2IDEAL FAN POWER, EFFICIENCY 3F12.4)
C
      RETURN
      END
C
      FUNCTION FG1(X,N,XT,YT,IX)
C
```

```
      DIMENSION XT(1),YT(1)                                             FG1 0040
C                                                                       FG1 0050
      IF (IX.LT.1) IX=1                                                 FG1 0060
      IF (IX.GT.N-1) IX=N-1                                             FG1 0070
      I=SIGN(1.0,X-XT(IX))                                              FG1 0080
 10   IF (IX.LT.1 .OR. IX.GE.N) GO TO 30                                FG1 0090
      IF (XT(IX).GT.X .OR. X.GT.XT(IX+1)) GO TO 20                      FG1 0100
      C=(X-XT(IX))/(XT(IX+1)-XT(IX))                                    FG1 0110
      GO TO 100                                                         FG1 0120
 20   IX=IX+I                                                           FG1 0130
      GO TO 10                                                          FG1 0140
 30   C=IX/N                                                            FG1 0150
      IX=IX-I                                                           FG1 0160
 100  FG1=YT(IX)+C*(YT(IX+1)-YT(IX))                                    FG1 0170
      RETURN                                                            FG1 0180
      END                                                               FG1 0190
C                                                                       INCN0010
      SUBROUTINE INCON (TIME)                                           INCN0020
C                                                                       INCN0030
      REAL*8 TICRD                                                      INCN0040
      INTEGER ON                                                        INCN0050
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT                                INCN0060
      COMMON/AXIS/NXYS(26)                                              INCN0070
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IYINCN0080
      COMMON /COLUMN/ IVERT,ILATRL                                      INCN0090
      COMMON /CONST/ PI,RAD,UO                                          INCN0100
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LCUVER,ACONTZ,ACONTW,ZEQUILINCN0110
     1 ,THEQL,ACBASE                                                    INCN0120
      COMMON /CURVE/NCURV(10)                                           INCN0130
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,     INCN0140
     ATIF(25),TIS(25)                                                   INCN0150
      COMMON /EQNCO/ NEQS,TCL(20),JQQ                                   INCN0160
      COMMON /FAIR/ RHOA,XLAERO                                         INCN0170
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,   INCN0180
     1 ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS                         INCN0190
     2 ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),    INCN0200
     3DETS(25),NS                                                       INCN0210
      COMMON / FRCUDE / FN,FNCRIT                                       INCN0220
      COMMON/GBOW/ XBOW                                                 INCN0230
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM     INCN0240
     1,DELS(4,10),XCP,ZCP                                               INCN0250
      COMMON /GEOMSW/ XAVG(10),DS                                       INCN0260
      COMMON/GRAF/NGRAF,NDRW                                            INCN0270
      COMMON /HEADG/TICRD(6)                                            INCN0280
      COMMON /PWAVE/ FNCON,PWVCON                                       INCN0290
      COMMON/LEAKER/ALEAK,BLEAK,CFSS,CFBS                               INCN0300
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  INCN0310
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-                 AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHG           INCN0320
 COMMON /MATRIX/ A(6,6)                                                 INCN0330
 COMMON /OPTION/ I3DOF,ISRGE,ITRIM,IDIA,IPITCH                          INCN0340
 COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT                                    INCN0350
 COMMON/PLVCCQ/NVI,NVD,NLI,NLD                                          INCN0360
 COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                          INCN0370
 COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,       INCN0380
-IRLD,IPROP,IAEROD,IRHS                                                 INCN0390
 COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7       INCN0400
 COMMON /ROLL/ PHIMAX,TROLL                                             INCN0410
 COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,       INCN0420
ARCLB,RTC,RUDANG,TIR(25)                                                INCN0430
 COMMON /RISER/ AMPTC                                                   INCN0440
 COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG INCN0450
1B(10),CENCAB                                                           INCN0460
 COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS                INCN0470
1 ,ELMAXS,YAVGS(10)                                                     INCN0480
 COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSWINCN0490
1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC          INCN0500
 COMMON/SLOPE/WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS                           INCN0510
 COMMON /STABLE/ S(4),ISTAB                                             INCN0520
 COMMON /STSLR/ CPHI,CPHID                                              INCN0530
 COMMON /SUM/ ISUM1(8),ISUM2(8)                                         INCN0540
 COMMON / VALOLD / YOLD(20)                                             INCN0550
 COMMON /VARBLE/ VAL(40)                                                INCN0560
 COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,            INCN0570
1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                    INCN0580
2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR               INCN0590
 COMMON /WAVEF/WAVLEN(10),OMEGAE(10),WAVSLP(10),ENCPER(10)              INCN0600
 COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,       INCN0610
1            AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),           INCN0620
2            AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                        INCN0630
3           ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                      INCN0640
4            AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),           INCN0650
5            AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                        INCN0660
6           ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                       INCN0670
7           ,BB(36),XREF,RX                                             INCN0680
 DIMENSION ZZZ(14050)                                                   INCN0690
 EQUIVALENCE (ZZZ,NAL)                                                  INCN0700
 EQUIVALENCE                (VAL(2),U),(VAL(3),V),(VAL(4),W),           INCN0710
1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),          INCN0720
2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),INCN0730
3(VAL(24),PB)                                                           INCN0740
 DIMENSION TEMP(7),XMO(10)                                              INCN0750
 DIMENSION TITLC(20)                                                    INCN0760
 DATA BEAM,BETAD,DELO,DELPI,DLRDO,DSO,ISYS,RMAXO,RCNO,RRATO,RREVO,      INCN0770
1 THETO,THSSI,TPRINO,UO,VXO,VZO,XBSI,XCPO,XLTOT,XPC,XRO,XSSI,YPO,       INCN0780
2 ZPC,ZRO,ZSSI/ 6*0.0,0,20*0.0/                                         INCN0790
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```
C                                                                        INCN0800
C      INITIAL CONDITIONS WITH WATSLP                                    INCN0810
C                                                                        INCN0820
       DO 9 I=1,8                                                        INCN0830
       ISUM1(I)=0                                                        INCN0840
     9 ISUM2(I)=0                                                        INCN0850
       PINF=2116.                                                        INCN0860
       RHOINF=.002378                                                    INCN0870
       GAM=1.4                                                           INCN0880
       ICLIT=600000
       GO TO 10                                                          INCN0890
  2200 READ(5,3000) NGRAF,NDRW                                           INCN0900
  3000 FORMAT(2I2)                                                       INCN0910
       READ(5,3001) NXYS                                                 INCN0920
  3001 FORMAT(26I2)                                                      INCN0930
       READ(5,3002) TICRD                                                INCN0940
  3002 FORMAT(6A8)                                                       INCN0950
10     READ(5,99) ISYSL,IOPT,(TEMP(I),I=1,7)                             INCN0960
       IF( ISYSL .EQ. ISYS .AND. ISYSL.EQ. 13) GOTO 70                   INCN0970
       ISYS=ISYSL                                                        INCN0980
       IF((ISYS.LE.0).OR.(ISYS.GT.22)) GO TO 70                          INCN0990
       GOTO(100,200,300,400,500,600,700,800,900,1000,1100,1200,1300,     INCN1000
      11400,1500,1600,1700,1800,1900,2000,2100,2200),ISYS                INCN1010
C                                                                        INCN1020
C      PROGRAM CONTROL PARAMETERS                                        INCN1030
C                                                                        INCN1040
100    CONTINUE                                                          INCN1050
       GOTO(101,102,103,104,105,106,107),IOPT
 101   CONTINUE                                                          INCN1070
       STIME=TEMP(1)                                                     INCN1080
       FTIME=TEMP(2)                                                     INCN1090
       DELC=TEMP(3)                                                      INCN1100
       DELPNT=TEMP(4)                                                    INCN1110
       TPRINO=TEMP(5)                                                    INCN1120
       IF (TPRINO.LT.STIME+DELPNT)  TPRINO = STIME+DELPNT                INCN1130
       IF (DELO.GT.DELPNT) DELO=DELPNT                                   INCN1140
       IF (DELC.EQ.0.0) GO TO 140                                        INCN1150
       GOTO 10                                                           INCN1160
  2000 READ(5,3003) NCURV                                                INCN1170
  3003 FORMAT(10I1)                                                      INCN1180
       GO TO 10                                                          INCN1190
  2100 READ(5,2210) ISUM1                                                INCN1200
       READ(5,2210)ISUM2                                                 INCN1210
  2210 FORMAT(8I2)                                                       INCN1220
       GO TO 10                                                          INCN1230
102    READ (5,191) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,  INCN1240
      1 IPROP,IAERCD,IRHS                                                INCN1250
       GOTO 10                                                           INCN1260
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 103   READ (5,175) NEQS,JQQ,(TOL(J),J=1,NEQS)                          INCN1270
       GOTO 10                                                          INCN1280
  104  READ(5,191) IVERT,ILATRL,NVD,NVI,NLD,NLI                         INCN1290
       GO TO 10                                                         INCN1300
  105  CONTINUE                                                         INCN1310
       I3DOF=TEMP(1)                                                    INCN1320
       ISRGE=TEMP(2)                                                    INCN1330
       ITRIM=TEMP(3)                                                    INCN1340
       IDIA=TEMP(4)                                                     INCN1350
       IPITCH=TEMP(5)                                                   ********
       GO TO 10                                                         INCN1360
   106 CONTINUE                                                         INCN1370
       PRCMO1=TEMP(1)                                                   INCN1380
       PRCMO2=TEMP(2)                                                   INCN1390
       PRCMO3=TEMP(3)                                                   INCN1400
       PRCMO4=TEMP(4)                                                   INCN1410
       PRCMO5=TEMP(5)                                                   INCN1420
       PRCMO6=TEMP(6)                                                   INCN1430
       PRCMO7=TEMP(7)                                                   INCN1440
       GO TO 10                                                         INCN1450
 107   CONTINUE                                                         INCN1451
       IF(TEMP(1).NE.0.)PINF=TEMP(1)                                    INCN1452
       IF(TEMP(2).NE.0.)RHOINF=TEMP(2)                                  INCN1453
       IF(TEMP(3).NE.0.)GAM=TEMP(3)                                     INCN1454
       READ(5,2041) IQUIT                                               INCN1455
  2041 FORMAT(I10)                                                      INCN1456
       GOTO 10                                                          INCN1457
   140 WRITE(6,195)                                                     INCN1460
       STOP                                                             INCN1470
C                                                                       INCN1480
C      MASS DISTRIBUTION                                                INCN1490
C                                                                       INCN1500
   200 G=32.17                                                          INCN1510
       RHC=1.99                                                         INCN1520
       HRHC=RHC/2.                                                      INCN1530
       GO TO (210,220,230), IOPT                                        INCN1540
   210 IMM = 0                                                          INCN1550
       WEIGHT = TEMP(1)                                                 INCN1560
       AM = WEIGHT/G                                                    INCN1570
       XS = TEMP(2)                                                     INCN1580
       ZS = TEMP(3)                                                     INCN1590
       AIXX = TEMP(4)                                                   INCN1600
       AIYY = TEMP(5)                                                   INCN1610
       AIZZ = TEMP(6)                                                   INCN1620
       AIXZ = TEMP(7)                                                   INCN1630
C                                                                       INCN1640
C      INERTIA MATRIX OPERATIONS                                        INCN1650
C                                                                       INCN1660
```

```
  212 DO 211 I=1,6
      DO 211 N=1,6
  211 A(I,N) = 0.0
      DO 213 N=1,3
  213 A(N,N)=AM
      A(4,4)=AIXX
      A(5,5)=AIYY
      A(6,6)=AIZZ
      A(4,6)=-AIXZ
      A(6,4)=-AIXZ
      AIMAX=AMAX1(AM,AIXX,AIYY,AIZZ,ABS(AIXZ))
      DO 214 I=1,6
      DO 214 J=1,6
  214 A(I,J)=A(I,J)/AIMAX
C
      CALL DMINV (A,6,D)
C
      DO 215 I=1,6
      DO 215 J=1,6
  215 A(I,J)=A(I,J)/AIMAX
      IF (D.NE.0.0) GO TO 10
      WRITE (6,216)
      STOP
C
C     READ WEIGHT DISTRIBUTION - ASSUME TRANSVERSE (PORT/STBD) SYMMETRY
C        X INPUT DIST. FWD. OF (SIDEWALL) TRANSOM
C        Y INPUT DIST. TO STARBOARD
C        Z INPUT DIST. UP FROM KEEL-LINE
C
  220 I = 1
  222 READ (5,192) AMI(I),XI(I),YI(I),ZI(I)
      IF (AMI(I).LT.0.0)  GO TO 224
      I = I+1
      IF ( I.GT.201 )  GO TO 70
      GO TO 222
  224 NMASS = I-1
      SUM = 0.0
      SUX = 0.0
      SUZ = 0.0
      DO 225 I=1,NMASS
      AMI(I) = AMI(I)/G
      SUM = SUM+AMI(I)
      SUX = SUX+AMI(I)*XI(I)
  225 SUZ = SUZ+AMI(I)*ZI(I)
      AM = SUM*2.0
      WEIGHT = AM*G
      ZS  = SUZ/SUM
      XS  = SUX/SUM
```

```
      SUM = 0.0                                                         INCN2150
      SUX = 0.0                                                         INCN2160
      SUY = 0.0                                                         INCN2170
      SUZ = 0.0                                                         INCN2180
      DO 226 I=1,NMASS                                                  INCN2190
      XI(I) = XI(I)-XS                                                  INCN2200
      ZI(I) = -ZI(I)+ZS                                                 INCN2210
      AMK = AMI(I)*2.0                                                  INCN2220
      SUX = SUX+AMK*XI(I)*XI(I)                                         INCN2230
      SUY = SUY+AMK*YI(I)*YI(I)                                         INCN2240
      SUZ = SUZ+AMK*ZI(I)*ZI(I)                                         INCN2250
  226 SUM = SUM+AMK*XI(I)*ZI(I)                                         INCN2260
      AIXX = SUY+SUZ                                                    INCN2270
      AIYY = SUX+SUZ                                                    INCN2280
      AIZZ = SUX+SUY                                                    INCN2290
      AIXZ = SUM                                                        INCN2300
      GO TO 212                                                         INCN2310
  230 GO TO 10                                                          INCN2320
C                                                                       INCN2330
C     XX AND YY TABLES                                                  INCN2340
C                                                                       INCN2350
300   CONTINUE                                                          INCN2360
      NSTA(1) = TEMP(1)                                                 INCN2370
      NSTA(2) = TEMP(2)                                                 INCN2380
      NSTA(3) = TEMP(3)                                                 INCN2390
      NSTA(4) = TEMP(4)                                                 INCN2400
      XLTOT=TEMP(5)                                                     INCN2410
      GOTO 10                                                           INCN2420
C                                                                       INCN2430
C     SIDEWALL (INCLUDING APPENDAGES)                                   INCN2440
C                                                                       INCN2450
400   CONTINUE                                                          INCN2460
      GOTO (401,402),IOPT                                               INCN2470
401   YSW=TEMP(1)                                                       INCN2480
      XLSW=TEMP(2)                                                      INCN2490
      CFSW=TEMP(3)                                                      INCN2500
      CDSW=TEMP(4)                                                      INCN2510
      AVBMSW=TEMP(5)                                                    INCN2520
      READ (10) ZZZ                                                     INCN2530
      REWIND 10                                                         INCN2540
      GOTO 10                                                           INCN2550
C                                                                       INCN2560
C    BLOCK 4 OPTION 2 REMOVED.       NO APENDAGES                       INCN2570
C                                                                       INCN2580
  402 CONTINUE                                                          INCN2590
      GOTO 10                                                           INCN2600
C                                                                       INCN2610
C     STERNSEAL                                                         INCN2620
```

```
C
500   CCNTINUE
      XSSI=TEMP(1)
      ZSSI=TEMP(2)
      ALEAK=TEMP(3)
      CFSS=TEMP(4)
      ELMAXS = TEMP(5)
      DFSS=TEMP(6)
      XLF=TEMP(7)
      ARGA = ELMAXS/XLF
      CCSTH = ARGA
      THSSI = ARCCS(ARGA)
      SINTH = SIN(THSSI)
      GC TO 10
C
C     BCWSEAL
C
 600  GC TO(610,620),IOPT
 610  CCNTINUE
      XBSI=TEMP(1)
      CFBS=TEMP(2)
      CPBS=TEMP(3)
      ZBSI=TEMP(4)
      ELMAXB = TEMP(5)
      XEF=TEMP(6)
      BLEAK=TEMP(7)
      GCTO 10
 620  CENCAB=TEMP(1)
      GC TO 10
C
C     PLENUM
C
700   CCNTINUE
      GC TO (705,710),IOPT
 705  CCNTINUE
      XLBW=TEMP(1)
      XEBW=TEMP(2)
      XPWV=TEMP(3)
      WIDTH=TEMP(4)
      XL=TEMP(5)
      XCPC=TEMP(6)
      BUBHGT=TEMP(7)
      XLXPWV=XLBW-XPWV
      PWVHT=(XPWV*XPWV-XLXPWV*XLXPWV)*.5/XL
      XPWVXS=XPWV-XS
      ABW=XBBW*XLBW
      AB=WIDTH*XL
      VCLNOM=(ABW+AB)*BUBHGT/2.
```

```
      GOTO 10
 710  CONTINUE
      FNCRIT=TEMP(1)
      GO TO 10
C
C     PROPULSION
C
800   CONTINUE
      GO TO (805,810),IOPT
 805  CONTINUE
      XPC=TEMP(1)
      YPC=TEMP(2)
      ZPC=TEMP(3)
      GO TO 10
C
C BLOCK 8 OPTION 2 REMOVED. ENGINE OUT INPUT IN BLOCK 16
C
  810 CONTINUE
      GOTO 10
C
C     RUDDER
C
900   CONTINUE
      GO TO (905,910,915),IOPT
  905 XRC = TEMP(1)
      YR=TEMP(2)
      ZRO = TEMP(3)
      RSPAN=TEMP(4)
      RASPR=TEMP(5)
      RAREA=TEMP(6)
      RCLB=2.*PI*RASPR/(RASPR+3.)
      RTC=TEMP(7)
      GO TO 10
C
C     910 NOT USED
C
  910 CONTINUE
      GO TO 10
 915  CONTINUE
      GOTO 10
C
C     AERODYNAMICS
C
1000  CONTINUE
      XLAERO=TEMP(1)
      BEAM=TEMP(2)
      RHOA=.5*RHOINF*XLAERO*BEAM
      GOTO 10
```

```
C
C      WAVES
C
1100   CONTINUE
       IWAVSW=IOPT
       IF(IWAVSW.GT.4) GO TO 70
       NWAVE=TEMP(1)
       IF(NWAVE .EQ. 0) GOTO 10
       IF(NWAVE .GT. 10) GOTO 70
       BETAD=TEMP(2)
       BETA=BETAD/RAD
       COSBET=COS(BETA)
       SINBET=SIN(BETA)
       TC = 1.0
       GO TO (1104,1106,1108,1108),IWAVSW
1104   DO 1105 I=1,NWAVE
1105   READ(5,1190) OMEGA(I),AW(I)
       GOTO 10
1106   DO 1107 I=1,NWAVE
1107   READ (5,1190) WAVLEN(I) ,AW(I)
       GOTO 10
 1108  SHTWV=TEMP(3)
       G1G=32.17
       G2=G1G*G1G
       G4=G2*G2
       GOTO(10,10,1110,1111),IWAVSW
 1110  CONTINUE
       PERL=TEMP(4)
       PERH=TEMP(5)
       WWN=(2.0*3.141592)*(1.0/PERH)
       WWX=(2.0*3.141592)*(1.0/PERL)
       GO TO 1112
 1111  CONTINUE
       WWN = TEMP(4)
       WWX = TEMP(5)
 1112  CONTINUE
       UUU=SQRT(SHTWV/0.0185)*1.6878
       UU4=UUU**4.
       CCC=(WWX/WWN)**(1./NWAVE)
       WWPO =WWN
       DO 1113 I = 1,NWAVE
       WWPN = WWPO*CCC
       WW =(WWPN+WWPO)/2
       DDW = WWPN-WWPO
       WWPO  = WWPN
       WW4= WW**4.0
       WW5 = WW**5.0
       SS = 0.0081*G2/(EXP(0.74*G4/(WW4*UU4))*WW5)
```

```
      OMEGA(I) =WW                                                      INCN4070
      AW(I) =  SQRT(2.*SS*DDW)                                          INCN4080
 1113 CONTINUE                                                          INCN4090
      GO TO 10                                                          INCN4100
C                                                                       INCN4110
C      INITIAL CONDITIONS                                               INCN4120
C                                                                       INCN4130
1200  CONTINUE                                                          INCN4140
      UO = TEMP(1)                                                      INCN4150
      THETO = TEMP(2)                                                   INCN4160
      DSC = TEMP(3)                                                     INCN4170
      DELPI=TEMP(4)                                                     INCN4180
      DPHI = TEMP(5)                                                    INCN4190
      GO TO 10                                                          INCN4200
1300  CONTINUE                                                          INCN4210
C                                                                       INCN4220
C      INPUT COMPLETED. 1) PRINT ALL INPUT                              INCN4230
C                                                                       INCN4240
      WRITE(6,2004) TITLC                                               INCN4250
      WRITE(6,2030) PINF,RHOINF,GAM                                     INCN4251
      WRITE (6,2001) STIME,FTIME,DELO,TPRINO,DELPNT                     INCN4260
      WRITE (6,2002) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,INCN4270
     1 IPROP,IAERCD,IRHS                                                INCN4280
      WRITE(6,2021) I3DOF,ISRGE,ITRIM,ICIA                              INCN4290
      WRITE (6,2029) PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7   INCN4300
      WRITE (6,2003) NEQS,  (TOL(J),J=1,NEQS)                           INCN4310
      WRITE (6,219) WEIGHT,XS,ZS,AIXX,AIYY,AIZZ,AIXZ                    INCN4320
      WRITE(6,217)A,AIMAX                                               INCN4330
      WRITE (6,2018) NSTA                                               INCN4340
      WRITE (6,490) YSW,XLSW,CFSW,CDSW,VANGLE,VSPAN,VCHCRD,VXO,VY,VZO,  INCN4350
     1 AVBMSW,VTC                                                       INCN4360
      WRITE (6,491) NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB     INCN4370
      IF (IMM.GT.0)  WRITE(6,1549)    (XMO(J),J=1,IMNX)                 INCN4380
      WRITE (6,1519) IMM,IMNX,IMNY,IBMFIL,BTIME,INT                     INCN4390
      IF (IMM.GT.0)  WRITE(6,1559) (YMI(J),J=1,IMNY)                    INCN4400
      WRITE (6,2010) XLBW,XBBW                                          INCN4410
      WRITE (6,2011) XL,WIDTH,XCPO,VOLNOM,BUBHGT                        INCN4420
      WRITE (6,2020) DELPI                                              INCN4430
      WRITE(6,2009) FNCRIT,XLTOT                                        INCN4440
      WRITE (6,2028) ENBFAN,BRPM,ENMFAN,EMRPM,ENSFAN,SRPM               INCN4450
      WRITE (6,2013) XRO,YR,ZRO,RONO,RMAXO,RRATO,RREVO,DLRDO            INCN4460
     1  ,RSPAN,RASPR,RAREA,RCLB,RTC                                     INCN4470
      WRITE (6,2012)        XPO,YPO,ZPO                                 INCN4480
      WRITE (6,2027) XLAERO,BEAM                                        INCN4490
      WRITE (6,2026) XBSI,CFBS,DPBS,ELMAXB                              INCN4500
      WRITE (6,2025) XSSI,ZSSI,ALEAK,CFSS,ELMAXS,CPSS,XLF               INCN4510
      WRITE (6,2017) UO,THETO,DSO                                       INCN4520
C                                                                       INCN4530
```

```
C                    AND 2) INITIALIZE VARIABLES FOR CALCS.
C
      DO 1302 I=1,40
 1302 VAL(I) = 0.0
      U = U0*1.6889
      XSS=-(XS-XSSI)
      ZSS=ZS-ZSSI
      THETA = THETO/RAD
      PHI = DPHI/RAD
      THEQL=THETA
      DS = DSC/12.
      Z=-ZS+DS
      ZEQUIL=Z
      PHIMAX=0.
      TROLL=0.
      IRDS=0
      TL=0.0
C
C     WAVE PARAMETERS TABLE
C
      IF(NWAVE .EQ.0) GOTO 1321
      AMPTC=1.30287
      GOTO(1310,1315),IWAVSW
 1310 DO 1311 I=1,NWAVE
 1311 WAVLEN(I)=2.*PI*G/(OMEGA(I)*OMEGA(I))
      GOTO 1317
 1315 DO 1316 I=1,NWAVE
 1316 OMEGA(I)=SQRT(2.*PI*G/WAVLEN(I))
 1317 CONTINUE
C
C     CALCULATE INITIAL FREQUENCIES OF ENCOUNTER
C
      DO 1318 I=1,NWAVE
      WAVSLP(I) = 360.0*AW(I)/WAVLEN(I)
      OMEGAE(I) =2.*PI*(SQRT(G*WAVLEN(I)/(2.*PI))-U*COSBET)/WAVLEN(I)
      ENCPER(I) = 2.0*PI/OMEGAE(I)
 1318 CONTINUE
      WRITE (6,1191) NWAVE,BETAD,(OMEGA(I),OMEGAE(I),WAVLEN(I),AW(I),
     1                WAVSLP(I),ENCPER(I),I=1,NWAVE)
      GOTO 1322
 1321 WRITE (6,1192)
 1322 CONTINUE
      DO 1303 I=1,4
      DO 1303 N=1,11
 1303 ETA(I,N) = 0.0
      DVCLW = 0.0
      FXWAV = 0.0
      FYWAV = 0.0
```

```
      FZWAV = 0.0                                           INCN5020
      FKWAV = 0.0                                           INCN5030
      FMWAV = 0.0                                           INCN5040
      FNWAV = 0.0                                           INCN5050
      ZBAR=Z                                                INCN5060
      PHIBAR=PHI                                            INCN5070
      THEBAR=THETA                                          INCN5080
      TIME=STIME                                            INCN5090
      DELT = DELO                                           INCN5100
      TPRINT=TPRINO-DELPNT                                  INCN5110
      PWVCON=4.*WEIGHT/(RHO*G*XLBW)                         INCN5120
      FNCON=SQRT(XLBW*G)                                    INCN5130
      VX=VXO-XS                                             INCN5140
      VZ = ZS-VZO                                           INCN5150
      XP=XPO-XS                                             INCN5160
      XR = XRC-XS                                           INCN5170
      YP=YPO                                                INCN5180
      ZP=ZS-ZPO                                             INCN5190
      ZR = ZS-ZRO                                           INCN5200
      IF (IMM.EQ. 0) GO TO 1305                             INCN5210
      DO 1304 J=1,IMNX                                      INCN5220
 1304 XMI(J) = XMC(J) - XS                                  INCN5230
 1305 CONTINUE                                              INCN5240
      XCP = XCPO-XS                                         INCN5250
      ZCP = ZS-BUBHGT                                       INCN5260
      XBS=XBSI-XS                                           INCN5270
      N=NSTA(3)                                             INCN5280
      ZBS=ZS-ZBSI                                           INCN5290
      DO 1364 J=1,N                                         INCN5300
      DELYBS=XBBW/(N-1)                                     INCN5310
       XX(3,J)=XBS-XSSI                                     INCN5320
      YY(3,J)=-0.5*XBBW+(J-1)*DELYBS                        INCN5330
 1364 CONTINUE                                              INCN5340
      N=N-1                                                 INCN5350
      DO 1367 J=1,N                                         INCN5360
      YAVGB(J)=(YY(3,J+1)+YY(3,J))/2.                       INCN5370
1367  CONTINUE                                              INCN5380
      N=NSTA(4)                                             INCN5390
      DELYSS=XBBW/(N-1)                                     INCN5400
      DO 1365 J=1,N                                         INCN5410
      XX(4,J)=-XS                                           INCN5420
      YY(4,J)=-.5*XBBW+(J-1)*DELYSS                         INCN5430
 1365 CONTINUE                                              INCN5440
      N=N-1                                                 INCN5450
      DO 1368 J=1,N                                         INCN5460
      YAVGS(J)=(YY(4,J+1)+YY(4,J))/2.                       INCN5470
 1368 CONTINUE                                              INCN5480
      XBOW=XLTOT-XS                                         INCN5490
```

```
      N=NSTA(1)
      DELX=XBSI/(N-1)
      DO 1309 J=1,2
      DO 1309 I=1,N
      XX(J,I)=(I-1)*DELX-XS
 1309 YY(J,I)= YSW*(2*J-3)
      WRITE(6,1366) ((XX(J,N),N=1,11),(YY(J,N),N=1,11),J=1,4)
 1366 FORMAT (//17H XX AND YY ARRAYS /14H PORT SIDEWALL /2(11F10.2/),
     1 15H STBD. SIDEWALL /2(11F10.2/),9H BOW SEAL /2(11F10.2/),
     2 11H STERN SEAL /2(11F10.2/))
      N=NSTA(1)-1
      DO 1308 I=1,N
 1308 XAVG(I)=DELX*(2*I-1)/2.-XS
C
      CALL WAVES(TIME)
C
C      INITIALIZE BUBBLE PRESSURE, ABSOLUTE (PSF)
C
      PB=PINF+DELPI
      PBBAR=DELPI
      PBAR=DELPI
      PSS=PB+DPSS
      PBS=PB+DPBS
      AB=ABW-(ABW-AB)*(ZS+Z/BUBHGT)
      CF=.37/((U/FNCON)**1.5655981)
      WATSLP=PBBAR*CF*PWVCON/WEIGHT
      IF (IDIA.EQ.1) GO TO 6
      VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVCLW
     1+.5*WATSLP*XL*AB
      GO TO 7
 6    VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVCLW+PBAR*.3175333
 7    CONTINUE
      BMASS=(PB/PINF)**(1./GAM)*VOL*RHOINF
      WRITE (6,2023)
      RETURN
C
C      RUN TERMINATOR
C
 1400 WRITE(6,98)
      STOP
C
C      BENDING MOMENT
C
 1500 GO TO (1510,1520,1530,1540), IOPT
 1510 IMM = TEMP(1)
      IF (IMM.GT.3)  GO TO 70
      IMNX = TEMP(2)
      IF (IMNX.GT.10)  GO TO 70
```

```
      IMNY = TEMP(3)
      IF (IMNY.GT.7)  GO TO 70
      IBMFIL = TEMP(4)
      BTIME = TEMP(5)
      IF (IMM.EQ.3)  IMT = TEMP(6)
      GO TO 10
 1520 DO 1521 J=1,7
 1521 XMO(J) = TEMP(J)
      IF (IMNX.LE.7)  GO TO 10
      READ 1522, (XMO(J),J=8,IMNX)
      GO TO 10
 1530 DO 1531 J=1,IMNY
 1531 YMI(J) = TEMP(J)
      GO TO 10
 1540 CONTINUE
      GO TO 10
1600  CONTINUE
      GO TO(1605,1610,1615),IOPT
 1605 CONTINUE
C
C   VALUES INPUT FOR STBD SCREW
C
      THST1=TEMP(1)
      NPS=TEMP(2)
      STHS=TEMP(3)
      IF(NPS.EQ.0.0) GO TO 1609
      READ(5,1950)(TIS(J),J=1,NPS)
      READ(5,1950)(THSTS(J),J=1,NPS)
      GO TO 10
 1609 THSTS(1)=THST1
 1610 CONTINUE
C
C   VALUES INPUT FOR PORT SCREW
C
      THST2=TEMP(1)
      NPP=TEMP(2)
      STHP=TEMP(3)
      IF(NPP.EQ.0.0) GO TO 1614
      READ(5,1950)(TIP(J),J=1,NPP)
      READ(5,1950)(THSTP(J),J=1,NPP)
      GO TO 10
 1614 THSTP(1)=THST2
 1615 CONTINUE
C
C   VALUES INPUT FOR RUDDER
C
      DELR=TEMP(1)
      NPR=TEMP(2)
```

```
      IF(NPR.EQ.0.0) GO TO 1616                                         INCN6460
      READ(5,1950)(TIR(J),J=1,NPR)                                      INCN6470
      READ(5,1950)(DELRUD(J),J=1,NPR)                                   INCN6480
      GO TO 10                                                          INCN6490
 1616 DELRUD(1)=DELR                                                    INCN6500
      GO TO 10                                                          INCN6510
 1700 GO TO (1705,1710),IOPT                                            INCN6520
 1705 NB=TEMP(1)                                                        INCN6530
      READ(5,1950)(TMEB(I),I=1,NB)                                      INCN6540
      READ(5,1950)(DELB(I),I=1,NB)                                      INCN6550
      GO TO 10                                                          INCN6560
 1710 NS=TEMP(1)                                                        INCN6570
      READ(5,1950)(TMES(I),I=1,NS)                                      INCN6580
      READ(5,1950)(DETS(I),I=1,NS)                                      INCN6590
      GOTO 10                                                           INCN6600
C                                                                       INCN6610
C     TITLE CARD (ALL 80 COLUMNS )                                      INCN6620
C                                                                       INCN6630
 1800 READ  (5,2022)  TITLC                                             INCN6640
      GO TO 10                                                          INCN6650
C                                                                       INCN6660
C     FAN MAPS                                                          INCN6670
C                                                                       INCN6680
1900  CONTINUE                                                          INCN6690
      GO TO (1905,1910,1915),IOPT                                       INCN6700
1905  CONTINUE                                                          INCN6710
      ENBFAN=TEMP(1)                                                    INCN6720
      BRPM=TEMP(2)                                                      INCN6730
      NPTSB=TEMP(3)                                                     INCN6740
      READIN=TEMP(4)                                                    INCN6750
      IF (READIN .EQ. 0.0) GO TO 10                                     INCN6760
      READ (5,1950) (PBFAN(J),J=1,NPTSB)                                INCN6770
      READ (5,1950) (QBFAN(J),J=1,NPTSB)                                INCN6780
      GO TO 10                                                          INCN6790
1910  CONTINUE                                                          INCN6800
      ENMFAN=TEMP(1)                                                    INCN6810
      EMRPM=TEMP(2)                                                     INCN6820
      NPTSM=TEMP(3)                                                     INCN6830
      READIN=TEMP(4)                                                    INCN6840
      IF (READIN .EQ. 0.0) GO TO 10                                     INCN6850
      READ (5,1950) (PMFAN(J),J=1,NPTSM)                                INCN6860
      READ (5,1950) (QMFAN(J),J=1,NPTSM)                                INCN6870
      GO TO 10                                                          INCN6880
1915  CONTINUE                                                          INCN6890
      ENSFAN=TEMP(1)                                                    INCN6900
      SRPM=TEMP(2)                                                      INCN6910
      NPTSS=TEMP(3)                                                     INCN6920
      READIN=TEMP(4)                                                    INCN6930
```

```
      IF (READIN .EQ. 0.0) GO TO 10                                    INCN6940
      READ (5,1950) (PSFAN(J),J=1,NPTSS)                               INCN6950
      READ (5,1950) (QSFAN(J),J=1,NPTSS)                               INCN6960
      GO TO 10                                                         INCN6970
1950  FORMAT(8F10.0)                                                   INCN6980
C                                                                      INCN6990
C     ERROR IN INPUT                                                   INCN7000
C                                                                      INCN7010
   70 CONTINUE                                                         INCN7020
      WRITE (6,79) ISYS                                                INCN7030
      STOP                                                             INCN7040
C                                                                      INCN7050
   79 FORMAT(34H INPUT ERROR - - - STOP - -  ISYS= ,I3)                INCN7060
   98 FORMAT(1H1,20(/),50X,19H COMPLETED ALL RUNS )                    INCN7070
99    FORMAT(I3,I2,7F10.0)                                             INCN7080
  191 FORMAT (16I5)                                                    INCN7090
  192 FORMAT (5F10.0)                                                  INCN7100
  195 FORMAT(///10X,65HERROR IN INPUT --- DELT AND/OR DELPNT EQUALS ZEROINCN7110
     1 --- JOB ABORTED )                                               INCN7120
  175 FORMAT (2I2/(8F10.0))                                            INCN7130
  216 FORMAT(///10X,82HERROR IN INPUT --- INPUT INERTIA ELEMENTS LEAD TOINCN7140
     1 ZERO DETERMINANT --- JOB ABORTED )                              INCN7150
  217 FORMAT(22H INERTIA MATRIX, AIMAX  6E15.4/(22X,6E15.4))           INCN7160
  219 FORMAT(30H WEIGHT, C.G., INERTIA MOMENTS 7F12.3)                 INCN7170
  305 FORMAT ( 11F7.0 )                                                INCN7180
  490 FORMAT(15H SIDEWALL INPUT 12(F8.3,1X))                           INCN7190
  491 FORMAT(26H SIDEWALL TABLE PARAMETERS 4(I4,F7.3,F7.3))            INCN7200
1190  FORMAT(2F10.0)                                                   INCN7210
 1191 FORMAT(/12HONO OF WAVES I2,10H BETA(DEG)F5.0/15H OMEGA(RAD/SEC) , INCN7220
     15X,16H OMEGAE(RAD/SEC) 5X,16H WAVE LENGTH(FT) 5X,14H AMPLITUDE(FT)INCN7230
     - 5X,16HMAX  SLOPE (DEG)5X,13HPERIOD,E(SEC)/(F8.4,12X,F8.4,4F20.3))INCN7240
 1192 FORMAT(/11HOCALM WATER)                                          INCN7250
 1519 FORMAT(32HOMOMENT CALC. CONTROL PARAMETERS 4I5, F8.3, I5 )       INCN7260
 1522 FORMAT ( 5X,7F10.0)                                              INCN7270
 1549 FORMAT(22H MOMENT CALCS. AT X OF 11F10.3)                        INCN7280
 1559 FORMAT(22H MOMENT CALCS. AT Y OF 11F10.3)                        INCN7290
 2004 FORMAT(33H1SES MOTIONS AND LOADS PROGRAM - 20A4,/)               INCN7300
 2001 FORMAT(23H START AND FINISH TIMES 2F10.2/                        INCN7310
     -22H INITIAL TIME INTERVAL F12.4/                                 INCN7320
     -18H START PRINTING AT F8.2,17H IN INCREMENTS OF F8.2)            INCN7330
 2002 FORMAT(24H INTERMEDIATE PRINT TAGS 16I5)                         INCN7340
 2003 FORMAT(39H NO. OF STATE EQUATIONS, AND TOLERANCESI5/(10X,10E12.2))INCN7350
 2009 FORMAT(23HOCRITICAL FROUDE NUMBER F15.4,5X,19H TOTAL CRAFT LENGTH INCN7360
     1          F15.4)                                                 INCN7370
 2010 FORMAT(34HOPLENUM, LENGTH AND WIDTH AT WATER 2F12.4)             INCN7380
 2011 FORMAT(34H PLENUM, LENGTH AND WIDTH AT HULL  2F12.4/             INCN7390
     -          35H PLENUM, CENTER OF PRESSURE AT HULL F12.4/          INCN7400
     -23H PLENUM, NOMINAL VOLUME F12.1,10X, 6HHEIGHT F12.4)            INCN7410
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 2012 FORMAT(/33H PROPULSION, X, Y, Z COORDINATES  3F12.4/)
 2013 FORMAT(/28H0RUDDER, X, Y, Z COORDINATES  3F12.4/
     -       41H RUDDER, ON, MAX, RATE, REVERSE, INITIAL  5F12.4/
     -       33H RUDDER,SPAN,ASPECT,AREA,CLB,T/C  5F12.4)
 2017 FORMAT(/39H0INITIAL CONDITIONS, VELOCITY (KNOTS) = F7.2, 5X,
     -       13HPITCH (DEG) = F8.3,5X,12HDRAFT (IN) = F8.2)
 2018 FORMAT( 49H NUMBER OF STATIONS, SIDEWALLS (F+S), SEALS (B+S) ,4I5)
 2020 FORMAT( 38H PLENUM, INITIAL PRESSURE, GAGE (PSF)  F8.2)
 2021 FORMAT(79H PROGRAM OPTION SWITCH SETTINGS (LATERAL PLANE,CONSTANT
     -SPEED,TRIM,MEMBRANE)     7I5)
 2022 FORMAT (20A4 )
 2023 FORMAT ( 1H1 )
 2025 FORMAT( 16H STERNSEAL INPUT  7F12.4 )
 2026 FORMAT( 16H BOWSEAL INPUT    7F12.4 )
 2027 FORMAT( 19H0AERODYNAMICS INPUT  7F12.4)
 2028 FORMAT( 33H0FANS, NO. + RPM, BOW,MAIN,STERN  3(F10.0,F10.1))
 2029 FORMAT(32H PROGRAM MODIFICATION SETTINGS         7(F12.4,1X))
2030  FORMAT(' PINF =',F8.2,5X,'RHOINF =',F10.7,5X,'GAM = ',F8.2/)
      END
C
      SUBROUTINE INTGRL (TIME)
C
      INTEGER ON
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,INT,XMI(10),YMI(7),IX,IY
      COMMON /EQNCO/ NEQS,TOL(20),JQQ
      COMMON /KSWTCH/ ITHRST
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /STABLE/ S(4),ISTAB
      COMMON/STEP/STEP2
      COMMON / VALOLD / YOLD(20)
      COMMON /VARBLE/ VAL(40)
      EQUIVALENCE (VAL(1),X),(VAL(2),Y(1))
      DIMENSION Y(20),ERROR(20)
      REAL K1(20),K2(20),K3(20),K4(20),K5(20)
      DATA IPASS/0/
C
      STEP2=1.0
      PB=VAL(24)
      BMASS=Y(10)
    1 IF((TIME+DELT).LE.TPRINT) GO TO 12
      DEL=DELT
      DELT=TPRINT-TIME
```

```
      IPASS=1
   12 X=TIME
      DO 2 J=1,NEQS
      Y(J)=YOLD(J)
    2 CONTINUE
      IFIRST=1
C
      CALL RHS(K1)
C
      IFIRST=2
      INT = 0
      IF (IACCEL.NE. ON) GO TO 14
      ACCLAT = (K1(2)+Y(1)*Y(6))/G
      WRITE  (6,101)  ACCLAT , DELT
 14   CN=2
  15  H=DELT/3.
      X=TIME+H
      DO 3 J=1,NEQS
    3 Y(J)=YOLD(J)+H*K1(J)
C
      CALL RHS(K2)
C
      DO 4 J=1,NEQS
    4 Y(J)=YOLD(J)+.5*H*(K1(J)+K2(J))
C
      CALL RHS(K3)
C
      X=TIME+.5*DELT
      DO 5 J=1,NEQS
    5 Y(J)=YOLD(J)+.375*H*(K1(J)+3.*K3(J))
C
      CALL RHS(K4)
C
      X=TIME+DELT
      DO 6 J=1,NEQS
    6 Y(J)=YOLD(J)+.5*H*(3.*K1(J)-9.*K3(J)+12.*K4(J))
C
      CALL RHS(K5)
C
      IF (JCQ.EQ. 1 ) GO TO 7
      DO 7 J=1,NEQS
      ERROR(J)=(K1(J)-4.5*K3(J)+4.*K4(J)-.5*K5(J))*H/5.0
      IF(ABS(ERROR(J)).GT.TOL(J)) GO TO 11
    7 CONTINUE
      DO 105 J=1,NEQS
      Y(J)=YOLD(J)+.5*H*(K1(J)+4.*K4(J)+K5(J))
  105 YOLD(J)=Y(J)
      TIME=TIME+DELT
```

```
      IF (IPASS.EQ.1) GO TO 8                                           INT 0770
      IF (JGQ.EQ. 1 ) GO TO 10                                          INT 0780
      DO 75 J=1,NEQS                                                    INT 0790
      IF(ABS(ERROR(J)).GT.TOL(J)/16.) GO TO 9                           INT 0800
   75 CONTINUE                                                          INT 0810
      DELT=2.*DELT                                                      INT 0820
      IF (DELT.GT.DELPNT) DELT=DELPNT                                   INT 0830
C                                                                       INT 0840
   10 RETURN                                                            INT 0850
C                                                                       INT 0860
    9 STEP2=DELT                                                        INT 0870
      GO TO 10                                                          INT 0880
    8 DELT=DEL                                                          INT 0890
      IPASS=0                                                           INT 0900
      GO TO 10                                                          INT 0910
   11 DELT=DELT/2.                                                      INT 0920
      IF (DELT.LT. 1.E-6 )  GO TO 25                                    INT 0930
      IF(JGQ.EQ.2) GO TO 26                                             INT 0940
                         WRITE (6,666) TIME,DELT,J,ERROR(J),TOL(J)      INT 0950
   27 IPASS=0                                                           INT 0960
      GO TO 15                                                          INT 0970
   26 STEP1=DELT*2.0                                                    INT 0980
      IF(STEP1.LT.STEP2)STEP2=STEP1                                     INT 0990
      GO TO 27                                                          INT 1000
   25 WRITE ( 6,150 )                                                   INT 1010
      WRITE (6,100) TIME,DELT,(K1(J),J=1,NEQS),VAL                      INT 1020
      CALL COLFIL                                                       INT 1021
      STOP                                                              INT 1030
C                                                                       INT 1040
  100 FORMAT(/10X,23HINTGRL TIME,DELT,K1,VAL /2E15.4/2(5E15.4/),5(8E15.4INT 1050
     1/))                                                               INT 1060
  101 FORMAT(1H0,9X,33HTOTAL LATERAL ACCELERATION (G) =    F12.4,       INT 1070
     112X,5HDT =  E15.4)                                                INT 1080
  150 FORMAT( 1H1,10X,44HDELTA TIME LESS THAN 1.0E-6  -  -  JOB STOPS )  INT 1090
  666 FORMAT(/10X,5HINT-J 2E30.5,I5,2E20.5)                             INT 1100
      END                                                               INT 1110
C                                                                       PROP0010
      SUBROUTINE PROP                                                   PROP0020
C                                                                       PROP0030
      INTEGER ON                                                        PROP0040
      COMMON /CONST/ PI,RAD,UO                                          PROP0050
      COMMON /FPROP/ FX,FY,FZ,FK,FM,FN                                  PROP0060
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,     PROP0070
     ATIP(25),TIS(25)                                                   PROP0080
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,  PROP0090
     -IRUD,IPROP,IAEROD,IRHS                                            PROP0100
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7  PROP0110
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      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,  PROP0120
     ARCLB,RTC,RUDANG,TIR(25)                                           PROP0130
      COMMON /VARBLE/ VAL(40)                                           PROP0140
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),       PROP0150
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),     PROP0160
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),PROP0170
     3(VAL(24),PB)                                                      PROP0180
      DIMENSION THS(1),THP(1),TS(1),TP(1),RUD(1),TR(1)                  PROP0190
      EQUIVALENCE (THSTS(1),THS(1)),(THSTP(1),THP(1)),(TIS(1),TS(1)),(TIPROP0200
     AP(1),TP(1)),(TIR(1),TR(1)),(DELRUD(1),RUD(1))                     PROP0210
C                                                                       PROP0220
      FX = 0.0                                                          PROP0230
      FY = 0.0                                                          PROP0240
      FZ = 0.0                                                          PROP0250
      FK = 0.0                                                          PROP0260
      FM = 0.0                                                          PROP0270
      FN = 0.0                                                          PROP0280
      TL=TIME                                                           PROP0290
      IF(NPR.EQ.0.0) GO TO 5                                            PROP0300
      RUDANG=FG1(TL,NPR,TR,RUD,IR)                                      PROP0310
      RUDANG=RUDANG/RAD                                                 PROP0320
C                                                                       PROP0330
C   CALCULATE THRUSTS AND MOMENTS INDIVIDUALLY                          PROP0340
C                                                                       PROP0350
      GO TO 6                                                           PROP0360
    5 RUDANG=DELRUD(1)                                                  PROP0370
      RUDANG=RUDANG/RAD                                                 PROP0380
    6 CD=COS(RUDANG)                                                    PROP0390
      SD=SIN(RUDANG)                                                    PROP0400
      IF(NPS.EQ.0.0) GO TO 2                                            PROP0410
      THSS=FG1(TL,NPS,TS,THS,IS)                                        PROP0420
      GO TO 4                                                           PROP0430
    2 THSS=THSTS(1)                                                     PROP0440
    4 IF(NPP.EQ.0.0) GO TO 3                                            PROP0450
      THSP=FG1(TL,NPP,TP,THP,IP)                                        PROP0460
      GO TO 1                                                           PROP0470
    3 THSP=THSTP(1)                                                     PROP0480
    1 STHSTS=STHS*THSS                                                  PROP0490
      STHSTP=STHP*THSP                                                  PROP0500
      FXS=THSS*CD+STHSTS*SD                                             PROP0510
      FXP=THSP*CD-STHSTP*SD                                             PROP0520
      FYS=-STHSTS*CD+THSS*SD                                            PROP0530
      FYP=STHSTP*CD+SD*THSP                                             PROP0540
      FZS=-THSS*THETA*CD-STHSTS*CD*PHI                                  PROP0550
      FZP=-THSP*THETA*CD+STHSTP*CD*PHI                                  PROP0560
      FX=FXP+FXS                                                        PROP0570
      FY=FYP+FYS                                                        PROP0580
      FZ=FZP+FZS                                                        PROP0590
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      FKP=-FZP*YP-FYP*ZP                                                PROP0600
      FKS=FZS*YP-FYS*ZP                                                 PROP0610
      FK=FKS+FKP                                                        PROP0620
      FMS=FZS*(-XP)+FXS*ZP                                              PROP0630
      FMP=FZP*(-XP)+FXP*ZP                                              PROP0640
      FM=FMS+FMP                                                        PROP0650
      FNS=-FXS*YP-FYS*(-XP)                                             PROP0660
      FNP=FXP*YP-FYP*(-XP)                                              PROP0670
      FN=FNS+FNP                                                        PROP0680
      IF (IPROP.NE.ON) RETURN                                           PROP0690
                  WRITE(6,123)                                          PROP0700
     1FX,FY,FZ,FK,FM,FN                                                 PROP0710
  123 FORMAT(/10X,22HPROP FX,FY,FZ,FK,FM,FN  /6E15.4)                   PROP0720
      RETURN                                                            PROP0730
      END                                                               PROP0740

      SUBROUTINE RHS(VALUE)                                             RHS 0020
C                                                                       RHS 0030
      INTEGER ON                                                        RHS 0040
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT                                RHS 0050
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,INT,XMI(10),YMI(7),IX,IYRHS 0060
      COMMON /COLUMN/ IVERT,ILATRL                                      RHS 0070
      COMMON /CONST/ PI,RAD,UO                                          RHS 0080
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LCUVER,ACONTZ,ACONTW,ZEQUILRHS 0090
     1 ,THEQL,ACBASE                                                    RHS 0100
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,     RHS 0110
     ATIP(25),TIS(25)                                                   RHS 0120
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,   RHS 0130
     1 ENSFAN,BRPM,MRPM,SRPM,NPTSB,NPTSM,NPTSS                          RHS 0140
     2 ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),    RHS 0150
     3DETS(25),NS                                                       RHS 0160
      COMMON /FAERO/ FXAED,FYAED,FZAED,FKAED,FMAED,FNAED                RHS 0170
      COMMON /FORBS/FXBS,FYBS,FZBS,FKBS,FMBS,FNBS,QLBS                  RHS 0180
      COMMON /FORSS/FXSS,FYSS,FZSS,FKSS,FMSS,FNSS,QLSS,FMS              RHS 0190
      COMMON /FPROP/ FXP,FYP,FZP,FKP,FMP,FNP                            RHS 0200
      COMMON / FROUDE / FN,FNCRIT                                       RHS 0210
      COMMON /FRUD/ FXRUD,FYRUD,FZRUD,FKRUD,FMRUD,FNRUD                 RHS 0220
      COMMON/GBOW/ XBOW                                                 RHS 0230
      COMMON /GEOM/     WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM    RHS 0240
     1,DELS(4,10),XCP,ZCP                                               RHS 0250
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)          RHS 0260
     1 ,DFBS(10),TSKIB(10)                                              RHS 0270
      COMMON /GEOMSS/DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10) RHS 0280
     1 ,ARM2S(10)                                                       RHS 0290
      COMMON /KSWTCH/ ITHRST                                            RHS 0300
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,  RHS 0310
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO       RHS 0320
      COMMON /MATRIX/ A(6,6)                                            RHS 0330
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      CCMMON /MSIDW/ DF(2,10),DSWAV(2,1C),FXH(2),FYH(2),FZH(2),FMH(2),
     1               FNH(2),VFY(2),VFZ(2),FXV
      CCMMCN /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)
      CCMMON /OPTION/I3DOF,ISRGE,ITRIM,IDIA,IPITCH
      CCMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT
      CCMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      CCMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUC,IPROP,IAEROD,IRHS
      CCMMCN /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      CCMMCN /PWAVE/ FNCON,PWVCON
      CCMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUCANG,TIR(25)
      CCMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC
      COMMON/SLOPE/WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS
      CCMMCN/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,CELYBS,DPBS,ELMAXB,YAVG
     1B(10),CENCAB
      CCMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS
     1 ,ELMAXS,YAVGS(10)
      CCMMON / VALOLD / YOLD(20)
      CCMMON /VARBLE/ VAL(40)
      CCMMON /WAVE/ ETA(4,11),AW(10),CMEGA(10),DVCLW,NWAVE,BETA,
     1                FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2               ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      EQUIVALENCE (VAL(18),FANPWR)
      EQUIVALENCE (VAL(35),PBARB),(VAL(36),PBARS)
      DATA NOTIN /0/
      DIMENSION ACCEL(3),ANGACL(3)
      DIMENSICN GF(6),VALUE(20)
C     WRITE (6,9876) (VAL(J),J=1,11)
C9876 FCRMAT ('0',11E12.5)
C
      DC 5 J=1,20
    5 VALUE(J)=0.0
C
C     CALCULATION OF BUBBLE WAVE MAKING DRAG
C
      AB=ABW-(ABW-(XL*WIDTH))*(ZS+Z)/BUBHGT
      IF (IDIA.EQ.1) GO TO 6
      FN=U/FNCON
      CF=.37/(FN**1.5655981)
      FXPWAV=-PWVCON*PBBAR*CF
      WATSLP=-FXPWAV/WEIGHT
      VCL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVOLW
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      1+.5*WATSLP*XL*AB                                                  RHS 0790
       GO TO 7                                                           RHS 0800
C                                                                        RHS 0810
C    MEMBRANE STUDY                                                      RHS 0820
C                                                                        RHS 0830
 6     PBAR=VAL(24)-PINF                                                 RHS 0840
       VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVCLW+PBAR*.3175333                 RHS 0850
 7     CONTINUE                                                          RHS 0860
       PB=PINF*(BMASS/(VOL*RHOINF))**GAM                                 RHS 0870
       PBS=PB+DPBS                                                       RHS 0880
       PSS=PB+DPSS                                                       RHS 0890
       PBAR=PB-PINF                                                      RHS 0900
       ABPB=PBAR*AB                                                      RHS 0910
                                                                         RHS 0920
C      CALCULATION OF BUBBLE WAVE MAKING DRAG                            RHS 0930
C                                                                        RHS 0940
       FLOW=SQRT(2.*ABS(PBAR)/RHOINF)*SIGN(1.,PBAR)                      RHS 0950
       QLSW=CFSW*ALSW*FLOW                                               RHS 0960
C                                                                        RHS 0970
       CALL BOWSL                                                        RHS 0980
       CALL STNSL                                                        RHS 0990
C                                                                        RHS 1000
       GF(1)=FXBS+FXSS+FXSW+FXRUD+FXP+FXWAV+FXAED          +FXPWAV       RHS 1010
       IF (ITHRST.NE.ITRIM) GO TO 11                                     RHS 1020
       THSTS(1)=THSTS(1)-GF(1)/2.                                        RHS 1030
       THSTP(1)=THSTP(1)-GF(1)/2.                                        RHS 1040
       THST=THSTS(1)+THSTP(1)                                            RHS 1050
       GF(1) = 0.0                                                       RHS 1060
   11  CONTINUE                                                          RHS 1070
       GF(2)=-R*U*AM+FYBS+FYSS+FYSW+FYRUD+FYP+FYWAV+FYAED                RHS 1080
       GF(3)=WEIGHT-ABPB       +FZBS+FZSS+FZSW+FZRUD+FZP+FZWAV+FZAEC     RHS 1090
       GF(4)=FKBS+FKSS+FKSW+FKRUD+FKP+FKWAV+FKAED +ABPB*PHI*(-Z)         RHS 1100
C                                                                        RHS 1110
C      CALCULATION OF EFFECTIVE CENTER OF PRESSURE                       RHS 1120
C                                                                        RHS 1130
       XCPU=XCP+0.001975*(U/1.6889-30.0)**2-0.974                        RHS 1140
       XCPC=SHXYAX(XCPU,ZCP,THETA,PI)                                    RHS 1150
       FMBUB=ABPB*XCPC                                                   RHS 1160
       GF(5)=FMBS+FMSS+FMSW+FMRUD+FMP+FMWAV+FMAED+FMBUB+FXPWAV*ZS        RHS 1170
       FWAVZ=FXPWAV*ZS                                                   RHS 1180
       GF(6)=FNBS+FNSS+FNSW+FNRUD+FNP+FNWAV+FNAED                        RHS 1190
       IF(I3DOF.NE.1.OR.I3DOF.NE.2.OR.I3DOF.NE.3) GO TO 100
       IF(I3DOF.NE.3) GF(3)=0.0
       GF(5)=0.0                                                         RHS 1220
  100  CONTINUE                                                          RHS 1230
       DO 1 I=1,6                                                        RHS 1240
       VALUE(I)=0.0                                                      RHS 1250
       DO 1 J=1,6                                                        RHS 1260
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      VALUE(I)=VALUE(I)+A(I,J)*GF(J)                                    RHS 1270
    1 CONTINUE                                                          RHS 1280
      IF(IPITCH.EQ.1) VALUE(4)=0.0
      VALUE(7)=P                                                        RHS 1290
      VALUE(8)=Q                                                        RHS 1300
      IF(IPITCH.EQ.1) VALUE(8)=0.0
      VALUE(9)=W                                                        RHS 1310
      IF (I3DOF .EQ. 1 ) GO TO 325                                      RHS 1320
C                                                                       RHS 1330
C     BUBBLE PRESSURE EQUATION                                          RHS 1340
C                                                                       RHS 1350
      QOUT=QLBS+QLSS+QLSW                                               RHS 1360
C                                                                       RHS 1370
      CALL FAN                                                          RHS 1380
C                                                                       RHS 1390
      QCNTRL=0.0                                                        RHS 1400
      VALUE(10)=RHOINF*(QIN-QOUT-QCNTRL)                                RHS 1410
      GO TO 236                                                         RHS 1420
  325 CONTINUE                                                          RHS 1430
      VALUE(10)=0.0                                                     RHS 1440
  236 CONTINUE                                                          RHS 1450
C                                                                       RHS 1460
C     WRITE DATA FILE FOR MOMENT AND SHEAR CALCS., IF REQUIRED          RHS 1470
C                                                                       RHS 1480
      IF ( IMT.NE.1 )  GO TO 111                                        RHS 1490
      NBS = NSTA(3)-1                                                   RHS 1500
      NSS = NSTA(4)-1                                                   RHS 1510
      NSSL = NSS/2+1                                                    RHS 1520
                    WRITE (IBMFIL)  (VAL(I),I=1,24),ZBAR,PHIBAR,THEBAR,RHS 1530
     -              FXW,FYW,FZW,FKW,FMW,FNW,  (VALUE(I),I=1,10),        RHS 1540
     -              DF,DSWAV,FXH,FYH,FZH,FMH,FNH,VFY,VFZ,FXV  ,         RHS 1550
     -              FXRUD,FYRUD,FXP,FYP,FZP,   FZSS,FKSS,FMSS,FXBS,FZBS,RHS 1560
     -              FXAED,FYAED,FZAED,FMAED,FNAED,FXPWAV,FXSS,FKBS,FMBSRHS 1570
     X ,FNBS,FNSS ,(TSKIS(I),DFSS(I),I=NSSL,NSS)                        RHS 1580
     Y             ,(TSKIB(I),DFBS(I),ARM1B(I),ARM2B(I),I=1,NBS)        RHS 1590
  111 CONTINUE                                                          RHS 1600
C                                                                       RHS 1610
C     CONSTANT LONGITUDINAL VELOCITY ( U )                              RHS 1620
C                                                                       RHS 1630
      IF (ISRGE .EQ.1) VALUE(1)=0.0                                     RHS 1640
C     WRITE (6,9875) (VALUE(IQX),IQX=1,10)
C9875 FORMAT (13X,10E12.5)
      IF (ON.NE.1) RETURN                                               RHS 1650
      DO 2 I=1,3                                                        RHS 1660
      ACCEL(I)=VALUE(I)/G                                               RHS 1670
      ANGACL(I)=VALUE(I+3)*RAD                                          RHS 1680
    2 CONTINUE                                                          RHS 1690
      BOWACC=ACCEL(3)-XBOW*VALUE(5)/G                                   RHS 1700
```

```
      STNACC=ACCEL(3)+XS*VALUE(5)/G
      IF(IVERT.NE.ON) GC TO 10
      ZC=Z+ZS
      VCLP=VCL
      THETAR=THETA*RAD
      QDEG=Q*RAD
   10 IF(ILATRL.NE.ON) GO TO 15
      DEPSI=PSI*RAD
      PDEG=P*RAD
      RDEG=R*RAD
      BETAS=-V/U*RAD
      ACCLAT=(VALUE(2)+U*R)/G
      DPHI=PHI*RAD
      DRFT=12.0*ZC
      VEL=U/1.6889
      DELRS=RUDANG*RAD
      IF(R.EQ.0.0) GO TO 115
      TRACUS=U/R
      GC TO 20
  115 TRACUS=1.E8
   20 WRITE(1)TIME,BMASS,DRFT,THETAR,PBAR,BOWACC,ACCEL(3),FANPWR,PBARB,P
     1BARS,VAL(16),VEL,PDEG,VOLP,X,Y,QIN,QOUT,GF(1),FXPWAV,THSTS(1),THST
     2P(1),QDEG,FZSS,FXSS,DPHI
   15 IF (IRHS .NE. ON) RETURN
       WRITE(6,77) FMBS,FMSS,FMSW,FMRUD,FMP,FMWAV,FMAED,FMBUB,FWAVZ
      WRITE(6,401)FXPWAV
      WRITE(6,200) PBAR,FANPWR,QIN,QLBS,QLSW,QLSS
      WRITE(6,215) AB,VOL
                   WRITE(6,213) VALUE,VAL
      WRITE(6,150) GF,ACCEL,ANGACL
      WRITE(6,175)BOWACC,STNACC
C
   77 FORMAT('0',6X,5HFMBS=,E16.6,2X,5HFMSS=,E16.6,2X,5HFMSW=,
     AE16.6,/,'0',6X,6HFMRUD=,E16.6,2X,4HFMP=,E16.6,2X,6HFMWAV=,E16.6,
     B/,'C',6X,6HFMAED=,E16.6,2X,6HFMBUB=,E16.6,2X,6HFWAVZ=,E16.6)
  401 FORMAT('0',6X,7HFXPWAV=,E16.6)
  200 FORMAT(//10X,3HRHS
     120H GAGE PRESS. (PSF) = F7.2,5X,21HFAN POWER REQD (HP) =  F8.2,
     25X,27HFAN FLOW RATE (CU FT/SEC) =  F9.2,
     3//31H LEAKAGE FLOW RATES (CU FT/SEC)  //11H BOW SEAL = F9.2,
     411H SIDEWALL = F9.2,13H STERN SEAL = F9.2)
  215 FORMAT(/13H PLENUM AREA= F9.2,10X,14HPLENUM VOLUME= F10.2)
  213 FORMAT(//12H VALUE ARRAY 2(/10E13.4)/10H VAL ARRAY 4(/10E13.4))
  150 FORMAT(/10X,24HTOTAL FORCES AND MOMENTS 6E12.4/10X,24HACCELERATION
     -S G,DEG/SEC2 6E12.4)
  175 FORMAT(/10X,16HBOW ACCEL. (G) = E12.4,21H   STERN ACCEL. (G) = E12
     -.4)
C
```

```
      RETURN
      END
C
      SUBROUTINE RUDDER
C
      INTEGER ON
      COMMON /CONST/ PI,RAD,UO
      COMMON /FRUD/ FX,FY,FZ,FK,FM,FN
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHC
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMC7
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,
     ARCLB,RTC,RUDANG,TIR(25)
      COMMON /VARBLE/ VAL(40)
      EQUIVALENCE (VAL(1),TIME),(VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      EQUIVALENCE (DELRUD(1),RUD(1)),(TIR(1),TR(1))
      DIMENSION RUD(1),TR(1)
      EQUIVALENCE (VAL(18),FANPWR)
      DATA END /1.28E-5/
C
C     CALCULATE PROGRAMMED RUDDER DEFLECTION
C
      TL=TIME
      IF(NPR.EQ.0.0) GO TO 5
      GO TO 6
    5 RUDANG=DELRUD(1)
      RUDANG=RUDANG/RAD
      GO TO 7
    6 RUDANG=FG1(TL,NPR,TR,RUD,IR)
      RUDANG=RUDANG/RAD
C
C     SIDE FORCE ON RUDDER
C
    7 DSR=Z+ZS-XR*THETA
      ENDFAC=(1.+DSR/(DSR+RSPAN))
      VH=V+XR*R-ZR*P
      QQ=HRHO*U*U*RAREA
      EFFANG=RUDANG-ENDFAC*VH/U
      FY=2.*QQ*ENDFAC*RCLB*EFFANG
C
C     DRAG FORCE ON RUDDER
C
```

```
      REY=U*(RAREA/RSPAN)/ENU
      CFR=.427/(ALOG10(REY)-.407)**2.64
      PI8=PI/8.
      CD=2.*CFR+ PI8*RTC*RTC*(1.+G*RSPAN/(U*U))+RCLB*EFFANG*EFFANG
      FX=-2.*CD*RAREA*HRHO*U*U
      FZ=0.
      FK=-ZR*FY
      FM=FX*ZR
      FN=XR*FY
      IF(IRUD.NE.ON) RETURN
                          WRITE(6,123)
     1FX,FY,FZ,FK,FM,FN
C
  123 FORMAT(/10X,24HRUDDER FX,FY,FZ,FK,FM,FN /6E15.4)
C
      RETURN
      END
C
      SUBROUTINE SAM
C
      WRITE (6,10)
   10 FORMAT (1H1,'YOU HAVE CALLED A DUMMY SAM SUBROUTINE.'/
     110X,'CHANGE TO BHISES TO USE THE SAM SUBROUTINE.')
      RETURN
      END

      SUBROUTINE SIDEWL
C
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,INT,XMI(10),YMI(7),IX,IY
      COMMON /CONST/ PI,RAD,U0
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM
     1,CELS(4,10),XCP,ZCP
      COMMON /GEOMSW/ XAVG(10),DS
      COMMON /KSWTCH/ ITHRST
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
      COMMON /MSIDW/ DF(2,10),DSWAV(2,10),FXH(2),FYH(2),FZH(2),FMH(2),
     1               FNH(2),VFY(2),VFZ(2),FXV
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON /SIDE/FX  ,FY  ,FZ  ,FK  ,FM  ,FN  ,ALSW,YSW,XLSW,CFSW,CDSW
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC
```

```
      COMMON /SLOPE/WATSLP,XPWV,XLXPWV,XPWVXS
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,
     1           AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),
     2           AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)
     3           ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),
     4           AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),
     5           AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)
     6           ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)
     7           ,BB(36),XREF,RX
      EQUIVALENCE              (VAL(2),U),(VAL(3),V),(VAL(4),W),
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),
     3(VAL(24),PB)
      DIMENSION GAP(2,11),DSW(2,11)
      DIMENSION FZHOLD(2), FZHDRP(2)
      DATA ENU /1.28E-5/
C
      PBAR=PB-PINF
      PBHEAD=PBAR/(RHO*G)
C
C     GAP OR WETTED DRAFT CALCULATION
C
      DO 10 J=1,2
      N=NSTA(J)
      DO 10 K=1,N
      DD=ZS+Z+YY(J,K)*PHI-XX(1,K)*THETA+ETA(J,K)
      DDIN=DD-WATSLP*(XPWVXS-XX(J,K))
      IF(DDIN.LT.BUBHGT) GO TO 101
      IF ( VAL(1)-TOLD .LT. DELPNT )  GO TO 101
      TOLD = VAL(1)
      WRITE (6,100) XX(J,K),VAL(1),DD
  100 FORMAT(/10X,43HWATER CONTACT WITH TOP OF BUBBLE CHAMBER AT F7.2,
     -14H FT.     TIME = F7.2,19H SEC.     IMMERSION= F7.2,4H FT. )
  101 CONTINUE
      DSW(J,K)=(SIGN(1.,DD)+1.)*DD/2.
      IF (DDIN) 6,8,8
    6 IF(DSW(J,K)-PBHEAD) 7,8,8
    7 GAP(J,K)=-DDIN*(1.-(DSW(J,K))/PBHEAD)
      GO TO 10
    8 GAP(J,K)=0.0
   10 CONTINUE
C
C     LEAKAGE AREA
C
```

```
      ALSW=0.0
      DO 20 J=1,2                                                       SDWL0710
      N=NSTA(J)-1                                                       SDWL0720
      DO 20 I=1,N                                                       SDWL0730
      ALSW=ALSW+(GAP(J,I)+GAP(J,I+1))*DELX/2.                           SDWL0740
   20 CONTINUE                                                          SDWL0750
C                                                                       SDWL0760
C     CROSS-FLOW DRAG ON SIDEWALLS                                      SDWL0770
C                                                                       SDWL0780
      FYD=0.0                                                           SDWL0790
      FKD=0.0                                                           SDWL0800
      FND=0.0                                                           SDWL0810
      DO 15 I=1,2                                                       SDWL0820
      N=NSTA(I)-1                                                       SDWL0830
      DO 15 J=1,N                                                       SDWL0840
      DSWAV(I,J)=(DSW(I,J)+DSW(I,J+1))/2.                               SDWL0850
      VREL      =V+XAVG(J)*R-(ZS-DSWAV(I,J)/2.)*P                       SDWL0860
      DF(I,J)=-   HRHO*CDSW*VREL      *ABS(VREL       )*DELX      *DSWAV(I,J)SDWL0870
      FYD=FYD+DF(I,J)                                                   SDWL0880
      FND=FND+DF(I,J)*XAVG(J)                                           SDWL0890
   15 FKD=FKD-(ZS-DSWAV(I,J)/2.)*DF(I,J)                                SDWL0900
C                                                                       SDWL0910
C     SET UP STERN LIMIT OF FORCE DETERMINATION                         SDWL0920
C                                                                       SDWL0930
      XSS = -XS                                                         SDWL0940
      GO TO 16                                                          SDWL0950
      ENTRY SIDWLM                                                      SDWL0960
      XSS = XMI(IX)                                                     SDWL0970
16    IP=1.+(THETA*RAD-STH)/DTH                                         SDWL0980
      IP=MAX0(MIN0(IP,NTH),1)                                           SDWL0990
      IP1=MIN0(IP+1,NTH)                                                SDWL1000
      DTHETA=(IP-1)*DTH+STH                                             SDWL1010
      DIP= (THETA*RAD-DTHETA)/DTH                                       SDWL1020
C                                                                       SDWL1030
C     CALC REYNOLDS NO. AND DRAG COEFF.                                 SDWL1040
C                                                                       SDWL1050
      REY=U*XLSW/ENU                                                    SDWL1060
      CDT=.427/(ALOG10(REY)-.407)**2.64                                 SDWL1070
C                                                                       SDWL1080
C     SIDEWALL FORCES, P/S                                              SDWL1090
C                                                                       SDWL1100
      DO 40 J=1,2                                                       SDWL1110
      WAREA=0.0                                                         SDWL1120
      N=NSTA(J)-1                                                       SDWL1130
      NI = (XSS+XS)*N/XLSW+1.5                                          SDWL1140
      DO 21 I=NI,N                                                      SDWL1150
      ZOR1=1.                                                           SDWL1160
      IF(DSWAV(J,I).EQ. 0.0) ZOR1=0.0                                   SDWL1170
```

```
21   WAREA=WAREA+DELX*(2.*DSWAV(J,I)+ZOR1*AVBMSW)
     FXH(J)=-   HRHO*CDT*WAREA*U*U
     FM1=2*J-3
     YLSW=FM1*YSW
     DS= Z    +ZS+YLSW*PHI
     DSS=DS-XSS*THETA
     ZOR1=(SIGN(1.,DSS)+1.)/2.
     DSS=DSS*ZOR1
     IDSS=1.5+(DSS-SBB)/DBB
     IDSS=MIN0(NBB,IDSS)
     BS=BB(IDSS)
     ZOR1=(SIGN(1.,DSS)+1.)/2.
     DSS=DSS*ZOR1
     DRBOW=DSS-(XX(J,N+1)-XSS)*THETA
     IF(DRBOW.LT.0.0) DRBOW=0.0
     A33S=(RHO*PI*BS**2)/8.
     A22S=(RHO*.4*PI*DSS**2)/2.
     IF(THETA.LT.0.0) A22S=.4*RHO*PI*DRBOW*DRBOW/2.
     DSR=DS-(XREF-XS)*THETA
     ID=1.+(DSR*12.-SDS)/DDS
     ID=MAX0(MIN0(ID,NDS),1)
     DDSR =(ID-1)*DDS +SDS
     ID1=MIN0(ID+1,NDS)
     DID= (DSR*12.-DDSR)/DDS
     BCO=ACO( 1,ID,IP)
     BC00=AC00( 1,ID,IP)
     BC2=AC2( 1,ID,IP)
     BC5 = AC5(1,ID,IP)
     BC6 = AC6(1,ID,IP)
     BCO =BCO +DID*(ACO (1,ID1,IP)-BCO ) +DIP*(ACO (1,ID,IP1)-BCO
    1    +DID*(ACO (1,ID1,IP1)-ACO (1,ID,IP1)-ACO (1,ID1,IP)+BCO ))
     BC00=BC00+DID*(AC00(1,ID1,IP)-BC00) +DIP*(AC00(1,ID,IP1)-BC00
    1    +DID*(AC00(1,ID1,IP1)-AC00(1,ID,IP1)-AC00(1,ID1,IP)+BC00))
     BC2 =BC2 +DID*(AC2 (1,ID1,IP)-BC2 ) +DIP*(AC2 (1,ID,IP1)-BC2
    1    +DID*(AC2 (1,ID1,IP1)-AC2 (1,ID,IP1)-AC2 (1,ID1,IP)+BC2 ))
     BC5 =BC5 +DID*(AC5 (1,ID1,IP)-BC5 ) +DIP*(AC5 (1,ID,IP1)-BC5
    1    +DID*(AC5 (1,ID1,IP1)-AC5 (1,ID,IP1)-AC5 (1,ID1,IP)+BC5 ))
     BC6 =BC6 +DID*(AC6 (1,ID1,IP)-BC6 ) +DIP*(AC6 (1,ID,IP1)-BC6
    1    +DID*(AC6 (1,ID1,IP1)-AC6 (1,ID,IP1)-AC6 (1,ID1,IP)+BC6 ))
C
C    SHIFT MOMENT CENTER FROM XREF TO C.G.
C
     BC00 = BC00-(XS-XREF)*BCO
     BC6  = BC6 -(XS-XREF)*BC5
C
C    HYDROSTATIC AND HYDRODYNAMIC FORCES
C
     FZH(J) =-G*BCO-U*U*A33S*THETA-U*A33S*W+Q*U*(-BC2+A33S*XSS)
```

```
     1   -U*A33S*P*YLSW                                                  SDWL1660
      FMH(J) =-U*XSS*XSS*A33S*Q+G*BC00+U*(A33S*XSS+BC2)*(W+U*THETA       SDWL1670
     1  +YLSW*P)                                                         SDWL1680
      FYH(J) =-A22S*U*(V+XSS*R   -ZS*P)                                  SDWL1690
      FNH(J) = FYH(J)*XSS-U*((V-ZS*P)*BC5+R*BC6)                         SDWL1700
C                                                                        SDWL1710
C     ADD VERTICAL FORCE DUE TO DEADRISE PROJECTION OF LATERAL FORCE     SDWL1720
C                                                                        SDWL1730
      DDRANG=0.0                                                         SDW*1740
      IF (DS.GT.0.5833) DDRANG=(DS-0.5833)*0.0629                        SDW*1750
      DRANG=1.021+DDRANG-PM1*PHI                                         SDW*1760
      CTNDR= COTAN(DRANG)                                                SDW*1770
      RUDSIG=SIGN(1.,RUDANG)                                             SDW*1780
      IF (RUDSIG.NE.PM1) CTNDR=PM1*TAN(PHI)                              SDW*1781
      FZHOLD(J)=FZH(J)                                                   SDWL1790
      FZHDRP(J)=PM1*FYH(J)*CTNDR*PROMO1                                  SDWL1800
      FZH(J)=FZH(J)+FZHDRP(J)                                            SDWL1810
      IF (IMT.EQ.2)  GO TO 40                                            SDWL1820
C                                                                        SDWL1830
C     CALC OF FORCE ON VENTRAL FINS REMOVED                              SDWL1840
C                                                                        SDWL1850
39    CONTINUE                                                           SDWL1860
40    CONTINUE                                                           SDWL1870
      IF (IMT.EQ.2) GO TO 41                                             SDWL1880
C                                                                        SDWL1890
C     TOTAL SIDEWALL FORCES AMD MOMENTS                                  SDWL1900
C                                                                        SDWL1910
      FX=FXH(1)+FXH(2)                                                   SDWL1920
      FY=FYH(1)+FYH(2)                                                   SDWL1930
      FZ=FZH(1)+FZH(2)                                                   SDWL1940
      FK=(FZH(2)-FZH(1))*YSW          +FKD -FY*ZS                        SDWL1950
      FY=FY+FYD                                                          SDWL1960
      FM=FMH(1)+FMH(2)+ZS*FX                                             SDWL1970
      FN= FND +FNH(1)+FNH(2) +(FXH(1)-FXH(2))*YSW                        SDWL1980
C                                                                        SDWL1990
C     DRAG FORCE ON FINS REMOVED                                         SDWL2000
C                                                                        SDWL2010
   41 CONTINUE                                                           SDWL2020
C                                                                        SDWL2030
C     ADD ROLL DAMPING DUE TO VERTICAL WAVE GENERATION                    SDWL2040
C                                                                        SDWL2050
      DSS=Z+ZS-XSS*THETA                                                 SDWL2060
      ZOR1=(SIGN(1.,DSS)+1.)/2.                                          SDWL2070
      DSS=DSS*ZOR1                                                       SDWL2080
      DS=Z+ZS                                                            SDWL2090
      DSR=DS-(XREF-XS)*THETA                                             SDWL2100
      ID=1.+(DSR*12.-SDS)/DDS                                            SDWL2110
      ID=MAXO(MINO(ID,NDS),1)                                            SDWL2120
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```
      DCSR=(ID-1)*DCS+SDS
      ID1=MINO(ID+1,NDS)
      DIC= (DSR*12.-DDSR)/DDS
      BC2=AC2(1,ID,IP)
      BC2=BC2  +DID*(AC2  (1,ID1,IP)-BC2  ) +DIP*(AC2  (1,ID,IP1)-BC2
     1    +DID*(AC2  (1,ID1,IP1)-AC2  (1,ID,IP1)-AC2  (1,ID1,IP)+BC2  ))
      FKCLD=FK
      FK=FK-PROMO2*YSW*YSW*BC2*P/PI
      FZH(1)=FZH(1)+PROMO2/2.*YSW*BC2*P/PI
      FZH(2)=FZH(2)-PROMO2/2.*YSW*BC2*P/PI
      IF(PROMO3.EQ.1.0) WRITE(6,200) VAL(1), FZHOLD(1), FZHCLC(2),
     1FZHDRP(1), FZHDRP(2), FZH(1), FZH(2), FKOLD, FK
  20C FORMAT(/2X,'TIME=',1X,E15.4,2X,'OLD VERTICAL FORCES',2(5X,E15.4)/
     125X,'VERTICAL DEADRISE FORCES',2(5X,E15.4)/25X,'NEW VERTICAL FORCE
     2S',2(5X,E15.4)/25X,'OLD AND NEW RCLL MOMENTS',2(5X,E15.4)/)
      IF (ISIDWL.NE.ON) RETURN
      DC 42 I=1,2
      DC 42 J=1,11
      GAP(I,J)=12.0*GAP(I,J)
   42 DSW(I,J)=12.0*DSW(I,J)
      WRITE( 6,123) ((GAP(I,J),J=1,11),I=1,2),((DSW(I,J),J=1,11),I=1,2),
     1 FX,FY,FZ,FK,FM,FN
C
  123 FORMAT(/10X,8HSIDEWALL /25H GAP (FT.) (STERN TO BOW) /14H PORT SID
     1EWALL /11F10.5/14H STBD SIDEWALL /11F10.5/37H IMMERSICN DEPTH (FT.
     2) (STERN TO BOW) /14H PORT SIDEWALL /11F10.5/14H STBC SIDEWALL /
     3 11F10.5/10X,26HSIDEWALL FX,FY,FZ,FK,FM,FN /6E15.4)
C
      RETURN
      END

C
      FUNCTION SHXYAX (X,Z,ANGYAX,PI)
C
      H=SQRT(X**2+Z**2)
      IF(X.EQ.0.0) GO TO 1
      ARG=Z/X
      ANGOLD=ATAN(ARG)
      IF(ANGOLD.GE.0.0) GO TO 2
      ANGNEW=ANGOLD+PI-ANGYAX
      GC TO 3
    1 ANGNEW=PI/2.0-ANGYAX
      GO TO 3
    2 ANGNEW=ANGOLD-ANGYAX
    3 SHXYAX=H*COS(ANGNEW)
C
      RETURN
      END
```

```
C
      SUBROUTINE STNSL
C
      INTEGER ON
      COMMON /AIR/ PINF,RHOINF,GAM,IQUIT
      COMMON /CONST/ PI,RAD,UO
      COMMON /FORSS/ FX,FY,FZ,FK,FM,FN,QL,FMS
      COMMON /GEOM/ WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM,DELS(4,
     110),XCP,ZCP
      COMMON /GEOMSS/ DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)
     1,ARM2S(10)
      COMMON /KSWTCH/ ITHRST
      COMMON /LEAKER/ ALEAK,CFSS
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHC,NMASS,AM
     1I(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,I
     1RUC,IPROP,IAEROD,IRHS
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON/SLOPE/WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS,ELMAXS,YAV
     1GS(10)
      COMMON /STSLR/ CPHI,CPHID
      COMMON /VALOLD/ YOLD(20)
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),CVCLW,NWAVE,BETA,FXWAV,FY
     1WAV,FZWAV,FKWAV,FMWAV,FNWAV,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PB
     2BAR
      EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VA
     1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VA
     2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)
     3, (VAL(24),PB)
      DIMENSION GAP(11), ELSKI(11), ELSKIL(11), AIRLEN(11), CTNSL(6,24)
      DATA ENU,UWSKI,CLSKI,GPS,HINGHT/1.28E-5,0.0,1.5708,.4644,1.875/
      DATA CTNSL/0.0,3.8,7.0,9.9,12.3,15.0,0.0,4.1,7.3,10.5,13.2,15.7,0.
     10,4.3,7.7,11.0,13.7,16.7,0.0,4.7,8.2,11.5,14.5,17.4,0.0,5.2,8.9,12
     2.4,15.4,18.3,0.0,5.5,9.4,13.1,16.1,19.2,0.0,5.8,9.9,13.8,17.1,20.6
     3,0.0,6.1,10.6,14.7,18.4,21.9,0.0,6.4,11.0,15.3,19.3,23.3,0.0,6.6,1
     41.7,16.4,20.5,24.5,0.0,6.9,12.3,17.6,22.1,25.7,0.0,7.2,13.5,19.6,2
     54.1,28.3,0.0,8.2,15.3,22.1,26.3,30.8,0.0,9.6,17.5,24.2,29.7,34.6,0
     6.0,11.9,20.0,25.4,32.3,38.0,0.0,14.0,23.3,30.0,35.8,41.0,0.0,17.5,
     725.5,32.5,39.7,44.5,0.0,21.6,30.0,38.7,42.0,47.0,0.0,24.6,33.7,41.
     80,45.0,48.7,0.0,28.3,38.5,45.0,48.7,48.7,0.0,35.0,45.0,48.7,48.7,4
     98.7,0.0,40.0,48.7,48.7,48.7,48.7,0.0,48.7,48.7,48.7,48.7,48.7,0.0,
     $48.7,48.7,48.7,48.7,48.7/
C
      IF (ELMAXS.GT.HINGHT) ELMAXS=HINGHT
      DO 1 J=1,11
```

```
      GAP(J) = 0.0
      ELSKI(J) = 0.0
      ELSKIL(J) = 0.0
      AIRLEN(J) = 0.0
    1 CONTINUE
C
C     'EFDEP' IS THE EFFECTIVE LIFTING DEPTH OF THE STERN SEAL
C
      EFDEP = 6.0
      MM = EFDEP
      ALSS = 0.0
      FX = 0.0
      FZ = 0.0
      FK = 0.0
      FM = 0.0
      FN = 0.0
      AGAP1 = 0.0
      AGAP2 = 0.0
      AGAPA1 = 0.0
      DELP = PSS-PB
      IF (DELP.LT.0.0) DELP=0.0
      PEAR = PB-PINF
C
C     CALCULATE ELSKI HERE.
C
      SINDIF = SINTH-COSTH*THETA
      COSDIF = COSTH+SINTH*THETA
      X1 = XSS+ZSS*THETA-XLF*SINDIF
      Z1 = (-Z-ZSS+XSS*THETA-ELMAXS*COS(THETA))
C
C     CALCULATE GAP HERE.
C
      N = NSTA(4)
      DO 2 K=1,N
      ELSKI(K) = (ETA(4,K)-DETADX(K)*(XX(4,K)-X1)-Z1)+YY(4,K)*PHI
     1-XPWV*WATSLP
      IF (ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT
      ELSKIL(K) = ELSKI(K)+GPS
      IF (ELSKIL(K).GT.HINGHT) ELSKIL(K)=HINGHT
      IF (ELSKIL(K).LT.(HINGHT-ELMAXS)) ELSKIL(K)=HINGHT-ELMAXS
      GAP(K) = -ELSKI(K)+(HINGHT-ELMAXS)
      IF (GAP(K).LT.0.0) GAP(K)=0.0
      MM1 = ELSKIL(K)*12.0
      MM2 = MM1+1
      MM3 = MM2+1
      DLINC = ELSKIL(K)*12.0-MM1
      STNSL1 = CTNSL(MM,MM2)
      STNSL2 = CTNSL(MM,MM3)
```

```
      AIRLEN(K) = ((STNSL2-STNSL1)*DLINC+STNSL1)/12.0
    2 CONTINUE
      N = NSTA(4)-1
      DO 5 J=1,N
      ELSKIA = (ELSKI(J+1)+ELSKI(J))/2.
      ELSKLA = (ELSKIL(J+1)+ELSKIL(J))/2.0
      AIRLAV = (AIRLEN(J+1)+AIRLEN(J))/2.0
      AGAP = ELSKLA-ELSKIA
      AGAP1 = AGAP
      IF (AGAP.LT.GPS) AGAP=GPS
      IF (AGAP1.GT.GPS) AGAP1=GPS
      ARM1S(J) = XX(4,J)+ELSKIA/2.
      ARM2S(J) = ZS-ELSKIA
      DFSS(J) = -DELP*DELYSS*AIRLAV/(GPS/AGAP)**2.0
      IF (AIRLAV.LE.0.0) GO TO 3
      ARG = .5*RHC*U*U*AIRLAV*DELYSS
      RESKI = U*AIRLAV/ENU
      CDTSKI = .427/(ALOG10(RESKI)-.407)**2.64
      TSKIS(J) = -ARG*CDTSKI
C
C     THE FOLLOWING CARD REMOVES WATER DRAG EFFECTS OF STERN SEAL
C
      TSKIS(J) = 0.0
      GO TO 4
    3 TSKIS(J) = 0.0
    4 CONTINUE
      FX = FX+TSKIS(J)
      FZ = FZ+DFSS(J)
      FK = FK+DFSS(J)*YAVGS(J)
      FM = FM-DFSS(J)*ARM1S(J)+TSKIS(J)*ARM2S(J)
      FN = FN-TSKIS(J)*YAVGS(J)
      ALSS = ALSS+(GAP(J)+GAP(J+1))*DELYSS/2.0
      AGAP2 = AGAP2+AGAP1
      AGAPA1 = AGAP2/J
    5 CONTINUE
      ALSS = ALSS+ALEAK*(AGAPA1/GPS)
      SQFAC = SQRT(2.*ABS(PBAR)/RHOINF)
      CL = CFSS*ALSS*SQFAC*SIGN(1.,PBAR)
      IF (ISTNSL.NE.ON) RETURN
      WRITE (6,6) GAP,AIRLEN,FX,FY,FZ,FK,FM,FN
C
    6 FORMAT (//12H  STERN SEAL/26H  GAP (FT.) PORT TO STBD. /11E11.3/28
     1H  AIRLEN(FT.) PORT TO STBD. /11E11.3/10X,23HSTNSL FX,FY,FZ,FK,FM,
     2FN/6E15.4)
C
      RETURN
      END
```

```
C
      FUNCTION T1(X)
C
      IF(ABS(X)-.1) 10,10,20
 10   T1=X*(1.-X*X/10.0)/3.
      RETURN
 20   T1=(SIN(X)-X*COS(X))/(X*X)
      RETURN
      END
C
      FUNCTION T2(X)
C
      IF(ABS(X)-.1) 10,10,20
10    T2=1.-X*X/6.
      RETURN
20    T2=SIN(X)/X
      RETURN
      END
C
      SUBROUTINE WAVES(TIME)
C
      INTEGER ON
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IY
      COMMON /CONST/ PI,RAD,U0
      COMMON /GEOM/    WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VCLNOM
     1,CELS(4,10),XCP,ZCP
      COMMON /GEOMBS/DETABX(11),DETABT(11),ARM1B(10),ARM2B(10)
     1 ,CFBS(10),TSKIB(10)
      COMMON /GEOMSS/DETACX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)
     1 ,ARM2S(10)
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHC
      COMMON /MWAVE/ FXW(2),FYW(2),FZW(2),FKW(2),FMW(2),FNW(2)
      COMMON /PLENUM/XLBW,XBBW,ABW,BUBHGT
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBCWSL,ISTNSL,IWAVES,
     -IRUD,IPROP,IAEROD,IRHS
      COMMON /PROMOD/ PROMO1,PROMO2,PROMO3,PROMO4,PROMO5,PROMO6,PROMO7
      COMMON /RISER/ AMPTC
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSW
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC
      COMMON /VARBLE/ VAL(40)
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVCLW,NWAVE,BETA,
     1              FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
     2              ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DCS,SDS,NTH,DTH,STH,NBB,DBB,SBB,
```

```
     1           AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),         WAVS0280
     2           AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                      WAVS0290
     3           ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                   WAVS0300
     4           AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),         WAVS0310
     5           AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                      WAVS0320
     6           ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                    WAVS0330
     7           ,BB(36),XREF,RX                                          WAVS0340
      DIMENSICN WC0(2),WC00(2),WC1(2),WC2(2),WC3(2),WC4(2),WC5(2),WC6(2)WAVS0350
     1          ,WC7(2),WC8(2)                                            WAVS0360
      DIMENSION WS0(2),WS00(2),WS1(2),WS2(2),WS3(2),WS4(2),WS5(2),WS6(2)WAVS0370
     1          ,WS7(2),WS8(2)                                            WAVS0380
      EQUIVALENCE              (VAL(2),U),(VAL(3),V),(VAL(4),W),          WAVS0390
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),       WAVS0400
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),WAVS0410
     3(VAL(24),PB)                                                        WAVS0420
      EQUIVALENCE (VAL(16),ETACG)                                         WAVS0430
C                                                                         WAVS0440
      IF (NWAVE.EQ.0) RETURN                                              WAVS0450
C                                                                         WAVS0460
C     CALCULATION OF SHIFT OF XCPO                                        WAVS0470
C                                                                         WAVS0480
      XCPU=XCP+0.001975*(U*0.5921-30.0)**2-0.974                          WAVS0490
      XCPC=SHXYAX(XCPU,ZCP,THETA,PI)                                      WAVS0500
      GAMMA=BETA-PSI                                                      WAVS0510
      SIGAM=SIN(GAMMA)                                                    WAVS0520
      COGAM=COS(GAMMA)                                                    WAVS0530
      FC= -X*COSBET -Y*SINBET                                             WAVS0540
      DVCLW=0.0                                                           WAVS0550
      ETACG=0.0                                                           WAVS0560
      N=NSTA(3)                                                           WAVS0570
      DO 1 J=1,N                                                          WAVS0580
      DETABX(J)=0.0                                                       WAVS0590
    1 CONTINUE                                                            WAVS0600
      N=NSTA(4)                                                           WAVS0610
      DO 2 J=1,N                                                          WAVS0620
      DETADX(J)=0.0                                                       WAVS0630
    2 CONTINUE                                                            WAVS0640
      DO 10 J=1,4                                                         WAVS0650
      N=NSTA(J)                                                           WAVS0660
      DO 10 K=1,N                                                         WAVS0670
   10 ETA(J,K)=0.0                                                        WAVS0680
      DO 15 J=1,2                                                         WAVS0690
      FXW(J) = 0.0                                                        WAVS0700
      FYW(J) = 0.0                                                        WAVS0710
      FZW(J) = 0.0                                                        WAVS0720
      FKW(J) = 0.0                                                        WAVS0730
      FMW(J) = 0.0                                                        WAVS0740
      FNW(J) = 0.0                                                        WAVS0750
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   15 CONTINUE                                                          WAVS0760
      XSS = -XS                                                         WAVS0770
      IF (IMT.EQ.2)  XSS = XMI(IX)                                      WAVS0780
      IP = 1   +(THEBAR*RAD-STH)/DTH                                    WAVS0790
      IP=MAXO(MINO(IP,NTH),1)                                           WAVS0800
      IP1=MINO(IP+1,NTH)                                                WAVS0810
      DTHETA=(IP-1)*DTH+STH                                             WAVS0820
      DIP= (THETA*RAD-DTHETA)/DTH                                       WAVS0830
C     TIME RISE FACTOR FOR WAVE AMPLITUDE                               WAVS0840
      AMPFAC=1.-EXP(-TIME/AMPTC)                                        WAVS0850
      DO 100 I=1,NWAVE                                                  WAVS0860
      OM1=OMEGA(I)                                                      WAVS0870
      OM2=OM1*OM1                                                       WAVS0880
      XWK=OM2/G                                                         WAVS0890
      AA=AW(I)*AMPFAC                                                   WAVS0900
      FT= OM1*TIME+XWK*FO                                               WAVS0910
      AL=XWK*COGAM                                                      WAVS0920
      IAA= 1+(ABS(AL)-SAL)/DAL                                          WAVS0930
      IAA=MAXO(MINO(IAA,NAL),1)                                         WAVS0940
      IAA1=MINO(IAA+1,NAL)                                              WAVS0950
      DAA= (IAA-1)*DAL+SAL                                              WAVS0960
      DIA= (ABS(AL)-DAA)/DAL                                            WAVS0970
      SALP=SIGN(1.,AL)                                                  WAVS0980
C                                                                       WAVS0990
C     WAVE FORCES AND MOMENTS ON THE SIDEWALLS                          WAVS1000
C                                                                       WAVS1010
      DO 40 J=1,2                                                       WAVS1020
      YLSW=(2*J-3)*YSW                                                  WAVS1030
      WE=FT+XWK*SIGAM*YLSW                                              WAVS1040
      ST=SIN(WE)                                                        WAVS1050
      CT=COS(WE)                                                        WAVS1060
      DS= ZBAR+ZS+YLSW*PHIBAR                                           WAVS1070
      DSR=DS-(XREF-XS)*THEBAR                                           WAVS1080
      ID=1.+(DSR*12.-SDS)/DDS                                           WAVS1090
      ID=MAXO(MINO(ID,NDS),1)                                           WAVS1100
      DDSR =(ID-1)*DDS +SDS                                             WAVS1110
      DID= (DSR*12.-DDSR)/DDS                                           WAVS1120
      ID1=MINO(ID+1,NDS)                                                WAVS1130
      DSS=DS-XSS*THEBAR                                                 WAVS1140
      ZOR1=(SIGN(1.,DSS)+1.)/2.                                         WAVS1150
      DSS=DSS*ZOR1                                                      WAVS1160
      IDSS=1.5+(DSS-SBB)/DBB                                            WAVS1170
      IDSS=MINO(NBB,IDSS)                                               WAVS1180
      BS=BB(IDSS)                                                       WAVS1190
      CK = COS(XWK*COGAM*XSS)                                           WAVS1200
      A33S=(RHO*PI*BS**2)/8.                                            WAVS1210
      SK = SIN(XWK*COGAM*XSS)                                           WAVS1220
      A22S=(RHO*.4*PI*DSS**2)/2.                                        WAVS1230
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      A42S=0.0                                                          WAVS1240
C                                                                       WAVS1250
C     INTERPOLATION OF WAVE TABLES                                      WAVS1260
C                                                                       WAVS1270
      K=1                                                               WAVS1280
      L=IAA                                                             WAVS1290
   41 CONTINUE                                                          WAVS1300
      BC0=AC0( L,ID,IP)                                                 WAVS1310
      BC00=AC00( L,ID,IP)                                               WAVS1320
      BC1=AC1( L,ID,IP)                                                 WAVS1330
      BC2=AC2( L,ID,IP)                                                 WAVS1340
      BC3=AC3( L,ID,IP)                                                 WAVS1350
      BC4=AC4( L,ID,IP)                                                 WAVS1360
      BC5=AC5( L,ID,IP)                                                 WAVS1370
      BC6=AC6( L,ID,IP)                                                 WAVS1380
      BC7=AC7( L,ID,IP)                                                 WAVS1390
      BC8=AC8( L,ID,IP)                                                 WAVS1400
      BS0=AS0( L,ID,IP)                                                 WAVS1410
      BS00=AS00( L,ID,IP)                                               WAVS1420
      BS1=AS1( L,ID,IP)                                                 WAVS1430
      BS2=AS2( L,ID,IP)                                                 WAVS1440
      BS3=AS3( L,ID,IP)                                                 WAVS1450
      BS4=AS4( L,ID,IP)                                                 WAVS1460
      BS5=AS5( L,ID,IP)                                                 WAVS1470
      BS6=AS6( L,ID,IP)                                                 WAVS1480
      BS7=AS7( L,ID,IP)                                                 WAVS1490
      BS8=AS8( L,ID,IP)                                                 WAVS1500
      WC0 (K)=BC0 +DID*(AC0 (L,ID1,IP)-BC0 ) +DIP*(AC0 (L,ID,IP1)-BC0   WAVS1510
     1   +DID*(AC0 (L,ID1,IP1)-AC0 (L,ID,IP1)-AC0 (L,ID1,IP)+BC0 ))     WAVS1520
      WC00(K)=BC00+DID*(AC00(L,ID1,IP)-BC00) +DIP*(AC00(L,ID,IP1)-BC00  WAVS1530
     1   +DID*(AC00(L,ID1,IP1)-AC00(L,ID,IP1)-AC00(L,ID1,IP)+BC00))     WAVS1540
      WC1 (K)=BC1 +DID*(AC1 (L,ID1,IP)-BC1 ) +DIP*(AC1 (L,ID,IP1)-BC1   WAVS1550
     1   +DID*(AC1 (L,ID1,IP1)-AC1 (L,ID,IP1)-AC1 (L,ID1,IP)+BC1 ))     WAVS1560
      WC2 (K)=BC2 +DID*(AC2 (L,ID1,IP)-BC2 ) +DIP*(AC2 (L,ID,IP1)-BC2   WAVS1570
     1   +DID*(AC2 (L,ID1,IP1)-AC2 (L,ID,IP1)-AC2 (L,ID1,IP)+BC2 ))     WAVS1580
      WC3 (K)=BC3 +DID*(AC3 (L,ID1,IP)-BC3 ) +DIP*(AC3 (L,ID,IP1)-BC3   WAVS1590
     1   +DID*(AC3 (L,ID1,IP1)-AC3 (L,ID,IP1)-AC3 (L,ID1,IP)+BC3 ))     WAVS1600
      WC4 (K)=BC4 +DID*(AC4 (L,ID1,IP)-BC4 ) +DIP*(AC4 (L,ID,IP1)-BC4   WAVS1610
     1   +DID*(AC4 (L,ID1,IP1)-AC4 (L,ID,IP1)-AC4 (L,ID1,IP)+BC4 ))     WAVS1620
      WC5 (K)=BC5 +DID*(AC5 (L,ID1,IP)-BC5 ) +DIP*(AC5 (L,ID,IP1)-BC5   WAVS1630
     1   +DID*(AC5 (L,ID1,IP1)-AC5 (L,ID,IP1)-AC5 (L,ID1,IP)+BC5 ))     WAVS1640
      WC6 (K)=BC6 +DID*(AC6 (L,ID1,IP)-BC6 ) +DIP*(AC6 (L,ID,IP1)-BC6   WAVS1650
     1   +DID*(AC6 (L,ID1,IP1)-AC6 (L,ID,IP1)-AC6 (L,ID1,IP)+BC6 ))     WAVS1660
      WC7 (K)=BC7 +DID*(AC7 (L,ID1,IP)-BC7 ) +DIP*(AC7 (L,ID,IP1)-BC7   WAVS1670
     1   +DID*(AC7 (L,ID1,IP1)-AC7 (L,ID,IP1)-AC7 (L,ID1,IP)+BC7 ))     WAVS1680
      WC8 (K)=BC8 +DID*(AC8 (L,ID1,IP)-BC8 ) +DIP*(AC8 (L,ID,IP1)-BC8   WAVS1690
     1   +DID*(AC8 (L,ID1,IP1)-AC8 (L,ID,IP1)-AC8 (L,ID1,IP)+BC8 ))     WAVS1700
      WS0 (K)=BS0 +DID*(AS0 (L,ID1,IP)-BS0 ) +DIP*(AS0 (L,ID,IP1)-BS0   WAVS1710
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```
     1     +DID*(ASO  (L,ID1,IP1)-ASO  (L,ID,IP1)-ASO  (L,ID1,IP )+BSO  ))        WAVS1720
      WSOO(K)=BSOO+DID*(ASOO(L,ID1, IP )-BSOO) +DIP*(ASOO(L,ID,IP1)-BSOO         WAVS1730
     1     +DID*(ASOO(L,ID1,IP1)-ASOO(L,ID,IP1)-ASOO(L,ID1,IP )+BSOO))           WAVS1740
      WS1  (K)=BS1  +DID*(AS1  (L,ID1, IP )-BS1  ) +DIP*(AS1  (L,ID,IP1)-BS1     WAVS1750
     1     +DID*(AS1  (L,ID1,IP1)-AS1  (L,ID,IP1)-AS1  (L,ID1,IP )+BS1  ))        WAVS1760
      WS2  (K)=BS2  +DID*(AS2  (L,ID1, IP )-BS2  ) +DIP*(AS2  (L,ID,IP1)-BS2     WAVS1770
     1     +DID*(AS2  (L,ID1,IP1)-AS2  (L,ID,IP1)-AS2  (L,ID1,IP )+BS2  ))        WAVS1780
      WS3  (K)=BS3  +DID*(AS3  (L,ID1, IP )-BS3  ) +DIP*(AS3  (L,ID,IP1)-BS3     WAVS1790
     1     +DID*(AS3  (L,ID1,IP1)-AS3  (L,ID,IP1)-AS3  (L,ID1,IP )+BS3  ))        WAVS1800
      WS4  (K)=BS4  +DID*(AS4  (L,ID1, IP )-BS4  ) +DIP*(AS4  (L,ID,IP1)-BS4     WAVS1810
     1     +DID*(AS4  (L,ID1,IP1)-AS4  (L,ID,IP1)-AS4  (L,ID1,IP )+BS4  ))        WAVS1820
      WS5  (K)=BS5  +DID*(AS5  (L,ID1, IP )-BS5  ) +DIP*(AS5  (L,ID,IP1)-BS5     WAVS1830
     1     +DID*(AS5  (L,ID1,IP1)-AS5  (L,ID,IP1)-AS5  (L,ID1,IP )+BS5  ))        WAVS1840
      WS6  (K)=BS6  +DID*(AS6  (L,ID1, IP )-BS6  ) +DIP*(AS6  (L,ID,IP1)-BS6     WAVS1850
     1     +DID*(AS6  (L,ID1,IP1)-AS6  (L,ID,IP1)-AS6  (L,ID1,IP )+BS6  ))        WAVS1860
      WS7  (K)=BS7  +DID*(AS7  (L,ID1, IP )-BS7  ) +DIP*(AS7  (L,ID,IP1)-BS7     WAVS1870
     1     +DID*(AS7  (L,ID1,IP1)-AS7  (L,ID,IP1)-AS7  (L,ID1,IP )+BS7  ))        WAVS1880
      WS8  (K)=BS8  +DID*(AS8  (L,ID1, IP )-BS8  ) +DIP*(AS8  (L,ID,IP1)-BS8     WAVS1890
     1     +DID*(AS8  (L,ID1,IP1)-AS8  (L,ID,IP1)-AS8  (L,ID1,IP )+BS8  ))        WAVS1900
      IF(K .EQ. 2) GOTO 42                                                     WAVS1910
      K=2                                                                      WAVS1920
      L =IAA1                                                                  WAVS1930
      GOTO 41                                                                  WAVS1940
42    BCO = WCO  (1)+DIA*(WCO  (2)-WCO  (1))                                   WAVS1950
      BCOO= WCOO(1)+DIA*(WCOO(2)-WCOO(1))                                      WAVS1960
      BC1 = WC1  (1)+DIA*(WC1  (2)-WC1  (1))                                   WAVS1970
      BC2 = WC2  (1)+DIA*(WC2  (2)-WC2  (1))                                   WAVS1980
      BC3 = WC3  (1)+DIA*(WC3  (2)-WC3  (1))                                   WAVS1990
      BC4 = WC4  (1)+DIA*(WC4  (2)-WC4  (1))                                   WAVS2000
      BC5 = WC5  (1)+DIA*(WC5  (2)-WC5  (1))                                   WAVS2010
      BC6 = WC6  (1)+DIA*(WC6  (2)-WC6  (1))                                   WAVS2020
      BC7 = WC7  (1)+DIA*(WC7  (2)-WC7  (1))                                   WAVS2030
      BC8 = WC8  (1)+DIA*(WC8  (2)-WC8  (1))                                   WAVS2040
      BSO =(WSO  (1)+DIA*(WSO  (2)-WSO  (1)))*SALP                             WAVS2050
      BSOO=(WSOO(1)+DIA*(WSOO(2)-WSOO(1)))*SALP                                WAVS2060
      BS1 =(WS1  (1)+DIA*(WS1  (2)-WS1  (1)))*SALP                             WAVS2070
      BS2 =(WS2  (1)+DIA*(WS2  (2)-WS2  (1)))*SALP                             WAVS2080
      BS3 =(WS3  (1)+DIA*(WS3  (2)-WS3  (1)))*SALP                             WAVS2090
      BS4 =(WS4  (1)+DIA*(WS4  (2)-WS4  (1)))*SALP                             WAVS2100
      BS5 =(WS5  (1)+DIA*(WS5  (2)-WS5  (1)))*SALP                             WAVS2110
      BS6 =(WS6  (1)+DIA*(WS6  (2)-WS6  (1)))*SALP                             WAVS2120
      BS7 =(WS7  (1)+DIA*(WS7  (2)-WS7  (1)))*SALP                             WAVS2130
      BS8 =(WS8  (1)+DIA*(WS8  (2)-WS8  (1)))*SALP                             WAVS2140
C                                                                              WAVS2150
C     SHIFT MOMENT CENTER FROM XREF TO C.G.                                    WAVS2160
C                                                                              WAVS2170
      BCCO = BCOO-(XS-XREF)*BCO                                                WAVS2180
      BC3  = BC3 -(XS-XREF)*BC1                                                WAVS2190
```

```
      BC4   = BC4 -(XS-XREF)*BC2                                          WAVS2200
      BC6   = BC6 -(XS-XREF)*BC5                                          WAVS2210
      BS00  = BS00-(XS-XREF)*BS0                                          WAVS2220
      BS3   = BS3 -(XS-XREF)*BS1                                          WAVS2230
      BS4   = BS4 -(XS-XREF)*BS2                                          WAVS2240
      BS6   = BS6 -(XS-XREF)*BS5                                          WAVS2250
C                                                                         WAVS2260
C     CALCULATE WAVE FORCES AND MOMENTS                                   WAVS2270
C                                                                         WAVS2280
      FZC= BS1-XWK*G*(BS2+BS0)-U*OM1*(-A33S*CK-AL*BS2)                    WAVS2290
      FZS= BC1-XWK*G*(BC2+BC0)+U*OM1*(-A33S*SK+AL*BC2)                    WAVS2300
      FMC= BS3-XWK*G*(BS4+BS00)-U*OM1*(-A33S*XSS*CK-BC2-AL*BS4)           WAVS2310
      FMS= BC3-XWK*G*(BC4+BC00)+U*OM1*(-A33S*XSS*SK-BS2+AL*BC4)           WAVS2320
      FYC= XWK*G*(BC5+BC0)-U*OM1*(-A22S*SK+AL*BC5)                        WAVS2330
      FYS= -XWK*G*(BS5+BS0)-U*OM1*(-A22S*CK-AL*BS5)                       WAVS2340
      FNC= XWK*G*(BC6+BC00)-U*OM1*(-A22S*XSS*SK-BS5+AL*BC6)               WAVS2350
      FNS= -XWK*G*(BS6+BS00)-U*OM1*(-A22S*XSS*CK-BC5-AL*BS6)              WAVS2360
      FKC=XWK*G*(BC7-BC8)+U*OM1*(-A42S*SK+AL*BC8)                         WAVS2370
      FKS= -XWK*G*(BS7-BS8)+U*OM1*(-A42S*CK-AL*BS8)                       WAVS2380
      FZW(J)=FZW(J)-AA*(FZC*CT+FZS*ST)                                    WAVS2390
      FMW(J)=FMW(J)+AA*(FMC*CT+FMS*ST)                                    WAVS2400
      FYW(J)=FYW(J)-AA*(FYC*CT+FYS*ST)*SIGAM                              WAVS2410
      FNW(J)=FNW(J)-AA*(FNC*CT+FNS*ST)*SIGAM                              WAVS2420
      FKW(J)=FKW(J)-AA*(FKC*CT+FKS*ST)*SIGAM                              WAVS2430
      FXW(J)= FXW(J)-2.*AA*RHO*G*BS*DSS*SK*CT                             WAVS2440
   40 CONTINUE                                                            WAVS2450
      IF (IMT.EQ.2)  GO TO 100                                            WAVS2460
C                                                                         WAVS2470
C     WAVE ELEVATION AROUND THE SIDEWALLS AND SEALS                       WAVS2480
C                                                                         WAVS2490
      DO 20 J=1,4                                                         WAVS2500
      N=NSTA(J)                                                           WAVS2510
      DO 20 K=1,N                                                         WAVS2520
      ETA(J,K)=ETA(J,K)+SIN(XWK*(- XX(J,K)*COGAM-YY(J,K)*SIGAM)+FT)*AA    WAVS2530
20    CONTINUE                                                            WAVS2540
      ETACG=ETACG+AA*SIN(FT)                                              WAVS2550
      N=NSTA(3)                                                           WAVS2560
      DO 25 J=1,N                                                         WAVS2570
      ARG=AA*COS(XWK*(-XX(3,J)*COGAM)+FT)                                 WAVS2580
      DETABX(J)=DETABX(J)-XWK*COGAM*ARG                                   WAVS2590
   25 CONTINUE                                                            WAVS2600
      N=NSTA(4)                                                           WAVS2610
      DO 30 J=1,N                                                         WAVS2620
      ARG=AA*COS( XWK*(-XX(4,J)*COGAM)+FT)                                WAVS2630
      DETADX(J)=DETADX(J)-XWK*COGAM*ARG                                   WAVS2640
   30 CONTINUE                                                            WAVS2650
C                                                                         WAVS2660
C     WAVE PUMPING                                                        WAVS2670
```

```
C
      X1=XWK*XLBW*COGAM/2.
      X2=XWK*XBBW*SIGAM/2.
      FTT=FT-XWK*XCPC*COGAM
      DVCLW=DVOLW+AA*ABW*T2(X1)*T2(X2)*SIN(FTT)
100   CCNTINUE
      IF (IMT.EQ.2)  RETURN
C
C     TCTAL WAVE FORCES AND MOMENTS
C
      FXWAV=FXW(1)+FXW(2)
      FYWAV=FYW(1)+FYW(2)
      FZWAV=FZW(1)+FZW(2)
      FKWAV=FKW(1)+FKW(2)+(FZW(2)-FZW(1))*YSW      +FYWAV*ZBAR
      FMWAV=FMW(1)+FMW(2)-FXWAV*ZBAR
      FNWAV=FNW(1)+FNW(2)+(FXW(1)-FXW(2))*YSW
      IF (IWAVES.NE.ON) RETURN
                 WRITE(6,200) ((ETA(I,J),J=1,11),I=1,4),ETACG,DVOLW
     1,FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV
C
  200 FCRMAT(/10X,5HWAVES /63H WAVE ELEVATIONS AT CRAFT STATIONS RELATIV
     1E TO CALM WATER (FT.) /14H PORT SICEWALL /11F10.5/14H STBC SICEWAL
     2L /11F10.5/9H BOW SEAL /11F10.5/11H STERN SEAL /11F10.5/25H WAVE E
     3LEVATION AT C.G. = F10.5,10X,43HPLENUM VOLUME LOST DUE TO WAVES (C
     4U. FT.) = F15.5/10X,23HWAVES FX,FY,FZ,FK,FM,FN /6E15.4)
C
      RETURN
      END
```

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